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OFFICIAL HISTORY OF THE WAR.
MEDICAL SERVICES.

DISEASES OF THE WAR. VOL. I.

CORRIGENDA.

(1) Page 4, line 40: For 59,750 read 57,684, and for 8,227 read 8,022.

(2) Page 11, last paragraph: For 209,404 read 208,226; for 59,750 read 57,684; for 8,227 read 8,022; for 285 read 229; and for 36 read 38·5.

(3) Page 275, line 16: Delete the words (10 grains).

(4) Page 275, line 29: For Carbonate of Ammonia . . . grains 20, read Carbonate of Ammonia . . . grains 5.

(5) Page 275, line 30: For Carbonate of Potash read Bicarbonate of Potash.

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HISTORY OF THE GREAT WAR

BASED ON OFFICIAL DOCUMENTS

MEDICAL SERVICES
DISEASES OF THE WAR

VOL. II

Including the Medical Aspects of Aviation and Gas
Warfare, and Gas Poisoning in Tanks and Mines.

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Note.—(T.) means temporary commission.
(T.F.) means Territorial Force commission.

PREFACE.

THE subjects with which this volume deals, like those of the first volume on the Diseases of the War, have been contributed by officers who had exceptional opportunities as consultants or specialists for observing the diseases and conditions which they describe. But in one or two instances their contributions have been considerably supplemented by others whose names do not appear in the list of contributors. This is specially so in the chapter on Neurasthenia and War Neuroses, in which most of the information relating to statistics and invalidism has been prepared by Sir Wilmot Herringham, mainly from figures obtained from the Ministry of Pensions. In this chapter, too, the account of the neurological hospitals in the United Kingdom is compiled from a report by the Medical Department of the War Office. Major Sydney Scott contributed the notes on the ear in relation to aviation. These notes had originally been prepared for the chapter on Injuries to the Ear in the second volume of the Surgery of the War, but the present volume was considered a more appropriate place for them.

The medical aspects of aviation and gas warfare form the chief subjects of the volume. Both provided new material for study by the medical services, and the experience gained during the war in connection with them is of permanent value. The physiological effects of flying and the physical standards required by aviators have now become a special subject of study by the medical profession, based mainly on the work done by the medical officers attached to the flying services during the war and on the scientific experiments of those who were associated with them. There was a demand during the war for some special record of the diseases due to flying, and after considerable correspondence between the Medical Advisory Board of the Air Ministry in London and the Director-General of the Medical Services in France it was decided to introduce into the official nomenclature of diseases a new series of conditions to be entered in all medical records under the heading of "Flying Sickness," which was to be regarded as a short synonym of morbid conditions due to flying, such as sickness at high altitudes, fainting in the air, cardio-vascular debility, exhaustion, vomiting and vertigo.

This addition to the nomenclature of diseases was published in an Army Council Instruction of 25th May, 1918, and affected the medical services in all theatres of war, as well as in the United Kingdom.

Probably no event of the war called for greater effort on the part of the medical services than did the onset of gas warfare. In the earliest stages it was the medical services, in association with physiological and chemical scientists, on whom the whole burden of combating this new weapon was laid, and up to October 1917, when the Ministry of Munitions took charge of the work, means for rendering innocuous each form of gas employed by the enemy were constantly being devised and tested under the general guidance of Colonel Sir Wm. Horrocks, the Chairman of the Anti-gas Committee at the War Office, while close observation was maintained on their application in the field by officers of the medical services in France and Belgium. The medical services may therefore justly claim to have played a major part in all that concerns the defensive side of gas warfare, and the history of its medical aspects consequently goes much deeper into the subject than it would have done had the medical services been concerned only with the symptoms and treatment of those who suffered from gas poisoning.

Although the names shown in the list of contributors to the chapters on gas warfare are those of the officers who dealt mainly with the subject of each chapter, the three contributors, Colonels Douglas, Elliott, and Soltau, collaborated in the preparation of them all.

Acknowledgments are due to the *Journal of the Royal Army Medical Corps*, the *British Journal of Surgery*, and the Medical Research Council, for permission to use the blocks of illustrations and coloured plates which have already appeared in their publications.

W. G. M.

March, 1922.

CHAPTER I.

NEURASTHENIA AND WAR NEUROSES.

NOTWITHSTANDING the excellent physique, the perfect training and the splendid *esprit de corps* of the men of the Expeditionary Force which went to France in 1914, it was soon demonstrated that there were limits to the powers of endurance of the human organism. Following the physical and mental strain of the retreat from Mons and the subsequent advance, there frequently appeared—as there has appeared in former campaigns—in addition to the physical exhaustion, a severe mental disability which rendered the individual affected temporarily, at any rate, incapable of further service.

It could, therefore, occasion no surprise when, from the rapidly enlisted and incompletely trained forces which were sent to the front, cases of mental breakdown were returned to the United Kingdom in very large numbers.

Since complete statistics are not yet available, it has been impossible to obtain any reliable evidence of the total number of cases of functional nervous disorders which occurred, but it has been possible to collect a few data showing the admissions to particular units at particular times.

The most complete statistics are those which have been obtained from the Ministry of Pensions, regarding the admissions, deaths, and invalidism from disease of the nervous system in the Gallipoli Expeditionary Force during 1915. These statistics are shown in Table II on p. 3.

Official medical statistics are available of the number of cases of functional nervous diseases diagnosed from the outbreak of war to the end of December 1914. They are as follows :—

TABLE I.

Functional Nervous Diseases amongst Imperial Troops, Aug. to Dec. 1914.

	United Kingdom.		France.	
	Officers.	Other Ranks.	Officers.	Other Ranks.
Neurasthenia	20	321	65	279
Traumatic neurasthenia	—	10	—	8
Hysteria	—	50	—	11
Shock	—	15	23	114
Shell shock	—	—	2	18
Totals	20	396	90	430

In addition to the above the following cases were associated with gunshot wounds:—

	Other ranks.
Neurasthenia	94
Traumatic neurasthenia	21
Hysteria	3
Shell shock	7
Total	125

In an official report written in December 1914, it is stated that 7 to 10 per cent. of all officers, and 3 to 4 per cent. of men admitted to hospitals in Boulogne were sent home suffering from the effects of nervous and mental shock, due to strain, stress and exhaustion.

The official statistics of the "shell shock" cases reported as battle casualties in France until the end of 1917 are also available, and are given in Table III on p. 4.

Since these cases were returned as "battle casualties," it is obvious that they all occurred in men exposed to hostile fire, but they do not include the large numbers who must have been evacuated as "sick," suffering from functional nervous diseases, but in whom there was not sufficient evidence that the disability was due to shell fire. Of these latter cases no figures are available. It is legitimate to assume that it was not until 1916 that functional nervous disorders assumed importance as a cause of wastage.

In the last sixteen months of the war the neurological centre dealing with the northern armies in France admitted 8,000 cases. Of these, about 40 per cent. were marked as battle casualties, though on a total of 353 officers only 22 per cent. were reported as battle casualties.

An officer who served in a neurological centre in one of the armies in France analysed two series of cases, each comprising 1,000 patients. The first series of cases was admitted to his wards during the period November 1916 to May 1917. The proportion of cases returned as battle casualties—those in whom there was definite evidence of concussion, being blown up or buried—was 16·8 per cent. The mean age of the patients was 26·8 years, but evidence was lacking as to the mean age in the armies from which the cases were drawn. Fifty per cent. of the patients had broken down before the end of the sixth month of exposure to shell fire. Of the total, 65 per cent. were returned to duty, and 35 per cent. evacuated to the base. Only fifteen cases returned to this centre after discharge to duty, but evidence was not available as to whether others might not have been sent to other medical units, though

TABLE II.

Summary of Admissions to Hospital, Deaths, and Invalidism for Diseases of the Nervous System in the Gallipoli Expeditionary Force during 1915.

Disabilities.	Deaths.		Invalided from Service.		Discharged to Duty, etc.		Total Admissions to Hospital.		Average number constantly in Hospital.*	
	Officers.	Other Ranks.	Officers.	Other Ranks.	Officers.	Other Ranks.	Officers.	Other Ranks.	Officers.	Other Ranks.
Neurasthenia, shell shock, hysteria, etc.	—	—	—	56	138	785	138	841	14·62	161·89
Epilepsy..	—	1	—	35	5	193	5	229	·65	35·21
Vertigo, headache, etc.	—	1	—	—	1	159	1	160	·02	10·07
Other diseases of the nervous system..	—	7	—	15	13	401	13	423	—	63·38
Mental diseases	—	2	—	19	2	51	2	72	—	19·72
TOTAL	—	11	—	125	159	1,589	159	1,725	15·29	290·27

---

* Calculated on an annual basis, and not according to duration of campaign.

TABLE III.

Record of Shell Shock Cases reported as Battle Casualties in France, not including Contingents from the Dominions.

	Sept. to Dec. 1914.		Jan. to June 1915.		July to Dec. 1915.		Jan. to June 1916.		July to Dec. 1916.		Jan. to June 1917.		July to Dec. 1917.		Total.	
	Officers.	Other Ranks	Officers.	Other Ranks	Officers.	Other Ranks	Officers.	Other Ranks	Officers.	Other Ranks	Officers.	Other Ranks	Officers.	Other Ranks	Officers.	Other Ranks.
Staff Officers ..	—	—	—	—	—	—	—	—	2	—	—	—	—	—	2	—
R.F.C.	—	—	—		—	—	—	—	1	2	—	4	2	7	3	13
Cavalry.. ..	—	1	—	3	1	1	3	36	2	18	6	17	1	25	13	101
R.A.	—	—	—	2	6	42	22	225	105	948	25	336	59	656	217	2,209
R.E.	—	—	—	3	6	30	13	132	17	391	9	68	6	134	51	758
Infantry ..	4	4	6	118	47	1,095	183	3,274	696	13,430	135	2,332	192	2,817	1,263	23,070
A.S.C.	—	—	—	3	—	4	—	10	3	48	1	9	2	40	6	114
R.A.M.C. ..	—	—	1	5	3	11	7	43	16	350	1	33	3	63	31	505
A.V.C.	—	—	—	—	—	—	—	1	—	1	1	—	—	—	1	2
A.O.C.	—	—	—	—	—	—	—	—	—	5	—	—	—	2	—	7
R.N. Division ..	—	—	—	—	—	—	—	2	5	98	1	32	2	27	8	159
Totals ..	4	5	7	134	63	1,183	228	3,723	847	15,291	179	2,831	267	3,771	1,595	26,938
	9		141		1,246		3,951		16,138		3,010		4,038		28,533	

the general opinion of those who served in France was that the percentage of relapse in cases treated early and effectively was small.

The second series comprised 1,030 cases admitted to the same centre between 20th November and 1st December, 1917. Of these, 91·4 per cent. were returned to duty and 8·6 per cent. evacuated to the base. Only five cases returned after discharge to duty, but this figure is open to the same criticism as the corresponding figure in the first series. The number of those who gave a history of having been previously in other hospitals with shell shock or neurasthenia was 212, or 20·5 per cent. The proportion of cases returned as battle

TABLE IV.

Personal History in Cases of Nervous Disorders.

	Organic*	Class A. Concussion admitted from the Line.	Class B. Nervous Breakdown in the Line.	Class C. Chronic Cases admitted from other Base Hospitals.
Average :—				
Age (in years)	30·9	26·3	28·6	30·5
Previous duration in hospital (in days)	63·0	0·0	0·0	70·8
Percentage :—				
Family history—				
Tuberculosis	13·4	17·4	26·9	24·3
Neurosis	24·7	25·0	55·9	47·9
Personal history (pre-war)—Neurosis	22·4	28·9	49·5	49·0
Personal history (army)—"shell shock"	14·1	25·3	59·1	42·5
Previously invalided for "shell shock"	6·0	11·3	18·2	23·1
Neurosis, not "shell shock"	9·9	2·6	28·2	59·9
Any previous personal history of neurosis ..	21·0	35·4	80·0	84·8
Number of Cases ..	105	81	95	469

* The column of organic nervous disease is given as a control.

casualties was 44 per cent. The mean age of the patients was 25·7 years. Fifty per cent. of the cases had broken down after exposure to shell fire for less than ten months.

Major Hurst, who was in charge of the neurological centre of the British Force in Macedonia, gives the following statistics :—

In a series of 750 cases admitted to his wards, 81 or 10 per cent. suffered from concussion in the line, 95 or 12·6 per cent. had nervous breakdown in the line, 469 or 62·5 per cent. were cases of neurosis transferred from other base hospitals, and 105 or 14 per cent. suffered from organic nervous diseases.

Of 211 cases, officers and other ranks, admitted from the front line, 87, or 41·2 per cent., suffered from concussion, and 124, or 58·7 per cent., suffered from nervous breakdown.

A further analysis of the 750 cases quoted above was made to determine the influence of previous personal history. (*See* Table IV).

The percentage of relapses which occurred in a period of 75 weeks amongst those of the 750 patients who were discharged from the neurological centre was: Class A, 3·7; Class B, 3·2; Class C, 8·1.

The following table was given by Major Hurst to show the period which elapsed after entry or re-entry after absence into the line before the patient broke down.

TABLE V.

Duration in Line previous to Breakdown or Shock, "Other Ranks" Cases admitted direct from Line.

History.	Percentage of Cases.			
	Concussion.		Nervous Breakdown.	
	7 Days or less before Breakdown or Shock.	28 Days or less before Breakdown or Shock.	7 Days or less before Breakdown or Shock.	28 Days or less before Breakdown or Shock.
Joining or rejoining unit from all absences	5·1	7·6	16·9	23·2
Coming under fire for first time ..	0·0	—	3·2	—
Rejoining unit after absence due to a preceding nervous breakdown ..	0·0	0·0	5·2	8·2
Number of Cases	81		95	

With the exception of this isolated group of figures from the Macedonian Force there are no statistics available to show the extent of the incidence of " shell shock " in other theatres of war than France. Even for France the statistics are inadequate to reveal completely what was the total wastage from troops owing to this cause. If returns had been systematically collected under this heading they would probably have been of great value in demonstrating how wastage from shell shock in any group of troops rose and fell, not only with the acute phases or the prolonged effort of battles, but also with the control exercised by battalion and other medical officers when the latter were properly informed of the methods to be employed in checking leakage and encouraging shell shock cases to return to duty.

The figures that are quoted later at any rate do not point to the occurrence of grave wastage from this cause. Thus Captain W. Johnson showed that in the arduous and prolonged fighting of the battles of Ypres in the autumn of 1917 the wastage during three months was less than 2 per cent. of the troops in action ; and Colonel Soltau's figures for admissions to casualty clearing stations in the Second Army throughout 1917 show that nervous disabilities returned as sick cases and not as battle casualties amounted to little more than 3 per cent. on a total of 106,000 admissions for all classes of sickness.

Table III gives a total of 28,533 cases of shell shock reported as battle casualties in France up to the end of 1917. If the number be doubled so as to include those reported as "sick" and an allowance added for 1918, the total of casualties from nervous disorders would probably be about 80,000, which would include many recurring admissions.

The admissions to the Maudsley Hospital in England, one of the two clearing stations through which passed most of the cases transferred to the United Kingdom from all theatres of war overseas, were 12,438 battle casualties and sick together for the period from October 1915 to end of 1919. This would suggest a total of perhaps 30,000 received in the United Kingdom, a number which corresponds in some degree to the estimate of cases occurring in France, for the numbers evacuated to the United Kingdom were known on occasions to have reached 40 per cent. of the reported casualties.

These very rough estimates are of serious importance in relation to the actual fact established by the Ministry of Pensions, namely, that even at the beginning of 1921 there were still 65,000 men receiving pensions for neurasthenic disablement of varying degrees attributed to "shell shock," and 50,000 at the beginning of 1922.

NERVOUS DISORDERS AS OBSERVED IN FRANCE.

During 1914 several men were evacuated from France to England owing to having been "broken" by their experiences in the retreat from Mons. Nervous disorders, therefore, were not unknown in the soldiers of the original expeditionary force. At the base hospitals, during the late autumn of 1914, Lieut.-Colonel Gordon Holmes saw frequent examples of gross hysterical conditions which were associated with trivial bullet and shell wounds, or even with only slight contusions of the back, arms or legs.

At the battle of Neuve Chapelle, in the spring of 1915, there was no appearance of such cases to any great extent. However, in the autumn of the same year, at the battle of Loos, something more serious was observed, and Captain Johnson recorded that at this time, while he was serving with a field ambulance, he personally saw and treated patients sent from the battle line with definite hysterical manifestations (mutism and tremors). These occurred chiefly, but not entirely, amongst the younger members of the new armies. During the winter of 1915–16 it was rare to see or hear of a case of psycho-neurosis in the forward area. But the occurrence of such cases in the armies of other nations during 1915 had compelled their authorities to take steps to deal with the problem. The French early sent medical experts to investigate the cases and to report on the conditions under which they arose. Special hospitals were provided, and the French neurologists and psychiatrists were not long in taking advantage of the opportunities thus given them. Their writings were among the first publications in which the psycho-neuroses of war were fully and accurately described.

The problem in the British Expeditionary Force did not become acute until July 1916, during the battle of the Somme. In the first few weeks several thousand soldiers were rapidly passed out of the battle zone on account of nervous disorders, and many of them were evacuated to England. When this great influx of patients arrived in England the term "shell shock" had become a generally recognized term, as if it were a new disease, although in fact exactly similar cases formed a well-recognized branch of medical practice before the war. Indeed, certain members of the profession lectured and wrote on the subject as if it were some new and mysterious malady. A complex terminology was evolved, and special treatments were manufactured in bewildering profusion. Some patients with hysterical symptoms were psycho-analysed, others with mental conflicts were hypnotized; whilst nearly all were treated on lines which could not fail to impress on the soldier's mind the mysteriousness of his malady. The case of two stretcher bearers in the battle of the Somme may serve as an example. They were not wounded, they were not "blown over" by a shell, but they were tired out and dispirited. As chance would have it, they happened to be engulfed in a swift line of evacuation to England, and within a week one of them sent back the information that they were both in a special hospital for "shell shock" in England, where "the windows were shaded with blue blinds and the walls were specially papered the same colour." There is little doubt that the same treatment would have converted others into the category of fit for "home service only." In fact, misguided public opinion had raised the psycho-neuroses to the dignity of a new war disease, before which doctors seemed well-nigh helpless. This view became rapidly widespread amongst the soldiers in France. Officers, men, and even in some instances medical officers, imbibed the new doctrine. It wrought untold evil amongst patients, and undoubtedly precipitated a breakdown in a certain type of man who might otherwise have held himself together. When a patient was brought to a neurological centre and was asked of what he complained, he almost invariably answered, "Shell shock, sir." To the soldier's mind it was as much an entity as scarlet fever, with the further addition that, being incurable, shell shock was more to be dreaded. In quite a number of cases the eradication of this false belief from the patient's mind was all that was needed to effect a rapid recovery from his symptoms. To explain to a man that his symptoms were the result of disordered emotional conditions due to his rough experiences in the line, and not, as he imagined, to some serious disturbance of his nervous system produced by bursting shells, became the most frequent and successful form of psychotherapy. The simplicity of its character in no way detracted from its value, and it not infrequently ended in the man coming forward voluntarily for duty, after having been given a much needed fortnight's rest in hospital.

All wounds and sickness in an army are a military problem. From this purely military point of view the psycho-neuroses presented exceptional difficulties. The experience in the first battle of the Somme had shown what a heavy degree of wastage from the fighting area these cases were capable of causing in the absence of special medical organization for dealing with them. And yet the army in France had hesitated to form special centres which, it was feared, might become homes for unpractical methods of treatment. And here can be seen the origin of the hostile attitude with which the whole subject was to some extent always regarded in France. Everyone in the fighting zone realized how thin was the line which separated the milder cases of psycho-neuroses (and these formed the majority of the patients) from those individuals whose disability lay in an insufficient stoutness of heart. The military school disputed the possibility of separating the one from the other, and took up the position that the establishment of special centres would open up a flood-gate for wastage from the army which no one would be able to control.

However, the severe wastage of man-power which the psycho-neuroses were causing in France made the problem of dealing with them urgent towards the end of 1916. The consulting neurologist, Lieut.-Colonel Gordon Holmes, and the consulting psychologist, Lieut.-Colonel C. S. Myers, recommended the institution of a special centre for diagnosis and treatment in each army area. These were opened after the battle of the Somme: a northern centre for the First and Second Armies at No. 4 Stationary Hospital, Arques; at No. 6 Stationary Hospital, Frévent, for the Third Army; at No. 3 Canadian Stationary Hospital in the citadel at Doullens for the Fifth Army; and at No. 21 Casualty Clearing Station, Corbie, for the Fourth Army.

These centres soon proved their usefulness, and in July 1917 a new centre for the Fifth Army was opened at No. 62 Casualty Clearing Station at Haringhe, near Roosbrugge, just prior to the battles of Ypres. This centre remained at Haringhe as the centre for the army occupying the left of the British line until the German offensive in 1918. The material afforded by these battles furnishes the bulk of the cases described below.

In October 1917 Lieut.-Colonel Myers proceeded to England, and from then onwards the direction of all the army centres was in the hands of Lieut.-Colonel Gordon Holmes. Under this unity of direction they were developed and organized along similar lines; and in the later stages of the war there existed one such forward centre for each army area. Any cases which these centres had to send down the line were evacuated to special neurological hospitals at the base, and in this way the whole subject remained under control. Due safeguards from the military point of view were imposed. The most far-reaching and important of these was the Adjutant-General's order, which laid down that " no patient who, without any visible wound, became non-effective from the effects of British or enemy weapons in action " was to be evacuated otherwise than into the special centre. Here a confidential report was made out for every patient admitted and sent to the man's commanding officer, who returned it as speedily as possible with all the information which he could supply concerning the circumstances under which the man had become a casualty. On this report was based the decision, which eventually had to be made, whether the man was " wounded " or " sick," *i.e.*, whether he was entitled to a wound record or not. Roughly speaking, 50 per cent. of the cases admitted during the period of severe fighting were in this way classified as " wounded," and the remainder as " sick." In the period of normal activity 40 per cent. were classified as " wounded," 60 per cent. as " sick."

The position taken up by the military authorities may be summed up thus. The psycho-neuroses cannot be ignored. Certain cases require medical care. The subject is, however, so bound up with the maintenance of *moral* in the army that every soldier who is non-effective owing to nervous breakdown must be made the subject of careful enquiry. In no case is he to be evacuated to the base unless his condition warrants such a procedure.

Organization of an Army Centre for Nervous Disorders.[*]

Each special centre was under the command of a lieutenant-colonel of the Royal Army Medical Corps, who was responsible for all administration. Treatment was entrusted to the specialist officers attached to the units ; but it was essential that the medical officers dealing with these patients should themselves possess the power of maintaining discipline. This aspect of the work was difficult for those in England to understand. They had no opportunity of appreciating the fact which, in France, was of the greatest importance, that the state of the majority of patients in the forward area required very little to turn the balance on the one hand to a rapid improvement, or on the other to a state of confirmed psychoneurosis. Those troops especially who had had but short periods of training were deficient in that moral conviction which it is the aim of discipline to establish. Further, it was found that, apart from his power of maintaining discipline, the medical officer required experience in neurology and psychological medicine, definite conceptions of treatment based upon that clinical experience and—perhaps even more important still—experience over a fairly lengthy period with fighting troops in the line. Such experience alone could give him a standard by which he could work and the courage to return others to those conditions from which he himself was for the time relieved.

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[*] These centres were designated N.Y.D.N. centres, the patients being sent to them under the nomenclature " not yet diagnosed (nervous)."

The following account is based on experience at the special centre of the Fifth Army in the Ypres area, between August 1917 and the date of the armistice in November 1918. It differs in no material way from the experiences in other army centres. The statistics analysed below deal only with the 8,000 patients admitted to this particular centre during the last sixteen months of the war.

The centre was situated some twelve miles behind the line, on the side of a main road and near a railway siding. Patients arrived by motor ambulance cars in small groups of six or twelve, and occasionally in convoys bringing forty or fifty cases. They came direct from field ambulances, where they might have passed anything from three or four to twenty-four hours. As a rule only twelve to forty-eight hours had elapsed since they left the line. The admission of patients in batches, which were frequently of considerable size, necessitated the organization of the centre on definite lines. This was arranged so as to ensure a careful segregation of one type of case from another. All cases on arrival were sent to an admission block, which varied in accommodation according to requirements. Here they were sorted out at the earliest possible moment into the following groups: (1) Simple exhaustion; (2) neurasthenia; (3) hysteria; (4) confusional and mental states; (5) miscellaneous medical conditions. Each group was kept distinct in separate wards. As recovery took place patients were passed into a convalescent block, which was divided into two portions—early convalescence and final convalescence. Those who did not improve within ten days, together with those who became worse, were evacuated to the base. The following plan indicates the organization.

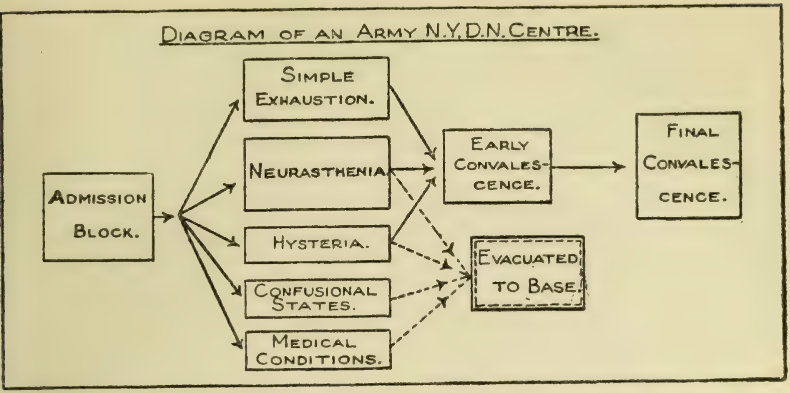

Fig. 1.—Organization of an army N.Y.D.N. Centre in No. 62 Casualty Clearing Station.

The convalescent block at any one time usually contained about three-fourths of the total patients in the centre. The men from the simple exhaustion group were transferred here direct from the admission block within three or four days of admission. Patients from the other groups were passed in as soon as they were considered fit for exercises. Every effort was made to make the atmosphere of the convalescent block sane and healthy. Discipline was revived and non-commissioned officer patients were placed in charge of the other patients. There was no daily round of medical inspection. Men who complained of illness reported sick in the ordinary way and were marched to the sick parade held by the medical officer in charge of convalescents. The remainder had definite hours for parade for the purpose of exercises and games—short hours for the early convalescent group and longer for the final convalescent group. A gymnastic and physical drill instructor, specially detailed by the army, was in charge of each of these two groups, and selected games and exercises suitable to the patients under his charge.

A large recreation room with indoor games was provided, also a lending library, and concerts were given regularly by a troupe of professional entertainers from amongst the patients. These, and similar means, proved to be great assets in helping on the work of the centre.

Some held the opinion that cases of psycho-neurosis should at once be removed from the noise of warfare into quiet habitations. This centre was for most of the time situated twelve to fifteen miles behind the line. A few men were adversely affected by the noise of guns and more particularly by practice ranges close by. Enemy aircraft at night also caused trouble; but on the whole the majority sustained no real harm. Those who were badly affected would in any case have needed evacuation to the base, and for the remainder a continuance in the forward area during the period of recuperation had much to be said in its favour. Had the course been taken of isolating the centre in some remote spot, it could only have resulted in helping to foster those false ideas, which so many patients possessed, that their disease was incurable. For a minority it might have been a beneficial measure, but for the majority it would have been inadvisable.

Organization at the Base for Nervous Disorders.

Shortly after the opening of the army centres, special hospitals at the base were detailed for the reception of all cases whom it was found necessary to evacuate from the army centres. This completed the arrangements for dealing with the nervous disorders in France. Henceforth, theoretically, it was impossible for any case of "nervous breakdown" to avoid the special line of evacuation which was provided; but indeed many did escape this control. Patients diagnosed as "debility," for example, were often admitted into casualty clearing stations in order to avoid the stigma which unhappily grew round the term N.Y.D.N., the only term under which patients could be admitted into an army neurological centre. In this way it became possible for cases of psycho-neurosis to reach England without passing through the special line of evacuation which the army provided.

On arrival at the neurological centres at the base the cases were grouped for disposal as follows:—

(1) Men to be sent to the United Kingdom. These were soldiers who had broken down under their experiences, and also men who were degenerate in type. Statistics show that only 4 to 10 per cent. of the patients admitted to the N.Y.D.N. centre in No. 62 Casualty Clearing Station were in this group.

(2) Men who, on account of their instability, had to be placed in a lower category, and were transferred to employment and labour companies in back areas.

(3) Men who needed further rest and training, and were sent to convalescent camps before returning to duty.

In addition, these special base hospitals were also centres for such cases as had reached the base without passing through the army N.Y.D.N. centres. It will be seen, therefore, that, except in certain abnormal periods of rush when medical accommodation was heavily overtaxed, a very small proportion of so-called "shell shock" cases required evacuation to the United Kingdom.

Sir F. W. Mott, in his introductory address to the War Neuroses Section at the British Medical Association's meeting in April 1919, stated that "according to his experience the most serious cases of war neurosis occurred in 1915 and 1916." He attributed this to the military conditions at that period, but the subsequent amelioration was probably due to the establishment of the army N.Y.D.N. centres, and of the special base hospitals in which patients were properly treated before the neuroses became deeply established.

Ætiology of Nervous Disorders of War.

After every one of the larger battles there occurred a rush of patients suffering from a psycho-neurosis of one form or another. Statistics showed that the smaller actions also produced their effect on the incidence of the disorder. The following curve of admissions to the N.Y.D.N. centre in No. 62 Casualty Clearing Station represents this, and illustrates how closely the maximum incidence of cases is related to periods of active fighting at the front.

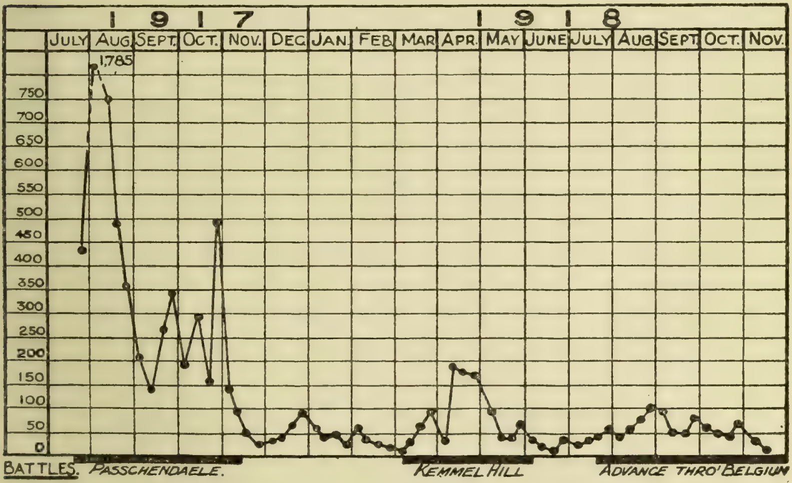

Chart I.—Showing the weekly admissions into the N.Y.D.N. centre in No. 62 Casualty Clearing Station from July 1917 to November 1918.

Owing to the nature of the military operations the period naturally divided itself into two parts, and this division serves to emphasize the important point that during a heavy battle a rush of comparatively mild cases occurred, whilst during periods of relative quiet on the army front the cases dropped to a numerically low level, but were on the whole of a severer type. This excess of milder cases admitted to the centre during the heavy fighting was sent down by the field ambulances more on account of the pressure on their accommodation than owing to any necessity from a medical point of view.

The first portion of the period comprised the months of August, September and October 1917—the period of the battles of Ypres. All soldiers who became incapacitated by nervous disorders in this period were passed into No. 62 Casualty Clearing Station. The total number admitted was just under 5,000, representing about 1·9 per cent. of all troops engaged. Considering the nature of the conditions in this battle area and the nerve-racking character of the struggle, this must be regarded as a very low figure.

The second portion of the period comprises the subsequent thirteen months—November 1917 to November 1918. Three thousand further cases were admitted during this time, the conditions of the army front being one of quietness, occasionally varied with short periods of marked activity. These two periods, therefore, provided some 8,000 cases, one part admitted during severe fighting, and the other during a non-battle period of activity on the front.

These observations serve to emphasize the facts that, although much has been written tending to multiply the causes of the nervous disorders of war, there were only two factors of overwhelming importance, namely, prolonged fighting and heavy bombardments, and that these rendered all other ætiological factors almost negligible. Wherever these acted together the incidence of the psycho-neuroses approached its maximum.

The type of warfare practised during the Somme battles of 1916 provided ideal conditions for the development of these disorders. The " artillery preparation " of the attacking force called for an " artillery reply " from the opposing side. This duel frequently lasted several hours or days, and during this period of waiting the nerves of all were kept on edge. Then after the attack came the reckoning of the losses amongst comrades ; and it was not unlikely that, owing to the call for troops, the whole acute process might soon be repeated.

Little by little men became worn down by such experience, and despite their best efforts the time would come when it was impossible to keep their thoughts from preying on the ordeals and sights of the battlefield. In such instances a breakdown occurred slowly; a gradual change would be noticed in the demeanour and behaviour of the patient, and he would eventually reach hospital with the report that he was "quite useless in the line." Another large group consisted of those cases in which a man suffering from an incipient "breakdown," or even to all appearances perfectly well, was suddenly faced with an experience of inexpressible horror which completely broke down his self-control. Such men have said afterwards, "It made me feel I had lost my senses." They were usually admitted into the centre in an acutely confused condition.

But besides the influence of the circumstances of war, the temperament of the individual soldier doubtless played a large part.

In the three months of the Ypres battles of 1917, 135 officers were admitted to No. 62 Casualty Clearing Station N.Y.D.N. Centre. This practically amounted to one "officer" patient to every 38 "other rank" patients. In the subsequent thirteen months 218 officers were admitted. This works out at roughly one "officer" patient to every 14 "other rank" patients, a high relative proportion for officers. The actual proportion of officers to other ranks in combatant formations was about 1 to 30.

Taking the whole sixteen months' period, analysis showed that of the total number of officers admitted, 22 per cent. were certified as having been buried or blown over by shells. This leaves 78 per cent. as having suffered from "breakdown" in the line, again showing a sharp comparison with the figures obtained in the case of other ranks. There it was found that the men "blown over" or "buried" and those "breaking down" in the line formed an almost equal proportion.

From this it was clear that cases amongst officers were in the second period relatively more frequent than among men, but less frequent during the period of severe fighting, and that emotional breakdowns from anxiety and strain were commoner than amongst other ranks. Further it was found that hysterical manifestations in officers were relatively rare. Of the 353 cases amongst officers only five required treatment for mutism, three needed isolation for obstinate hysterical tremors, and two called for treatment for some form of hysterical walk. This, however, may not be unconnected with the fact that relatively fewer officers admitted had been " blown up," although it still forms a point of great interest as an observation on hysteria. Non-commissioned officers, too, shared this relative freedom from hysterical states. Any soldier above the rank of corporal seemed possessed of too much dignity to become hysterical. On the other hand, amongst officers the emotional breakdowns tended to be more profound and intractable than amongst the other ranks. In fact, the severest forms of psychasthenia were seen amongst officer patients.

The life of an average soldier throws some light on the onset of psycho-neuroses. The average individual in possession of an average physical and mental development and fired by the motive of "seeing his country through" was able for a time successfully to sustain both the rigours of modern offensive warfare and the still more exacting rigours of military discipline. Sooner or later the periods of physical and emotional stress through which he passed began to tell, and the stage was reached when, if the individual alone could be considered, a rest became imperative. For various reasons this might not at the moment be possible, and the man was compelled to push himself to breaking point. Even when this happened, a short period of rest behind the line was all that was usually necessary in order to restore him to a state in which he could " carry on." Those who had any experience in the various divisional and corps rest stations scattered up and down behind the front knew this type of man well, and had many opportunities of admiring the grit which refused to allow him to stay in hospital a day longer than was necessary.

Very different from this type, on the other hand, was the soldier who was below the average—the physical degenerate and the neuropath. He reached the limit of his reserve power much more quickly, and his breakdown, when it came, was of a more serious and lasting character.

There was also a class of men who were once sturdy soldiers but had been broken by wounds, sickness and the length of their service in the battle line. With a nervous laugh they would say they no longer felt sure of themselves and dreaded a possible breakdown before the eyes of their comrades. To these men great sympathy was due.

Pathology.

It is noteworthy that, amongst the thousands of patients examined, only some 2·5 per cent. showed evidence of a possible lesion of the nervous system. This in itself is clear evidence of the "emotional" origin of nearly all the cases of war psycho-neuroses, and it is amply confirmed by the paucity of the *post-mortem* evidence which the centre supplied. In only two cases, at autopsy, was a condition found which might be supposed to result from the effects of a high explosive on the central nervous system. Unfortunately both cases were admitted in a comatose state, death resulting in a few hours, and no history was obtained with them. Their ages were between 20 and 25 years. In both cases a large cerebral hæmorrhage was discovered without the source of the hæmorrhage being apparent. In one case the whole of one lateral ventricle was filled with blood-clot, and in the other the third ventricle was partially filled as well. There was no external wound or contusion, and examination of the organs of the body revealed no macroscopical changes.

It must be remembered, however, that the majority of unconscious patients suffering from concussion were classified as "surgical," and accordingly were sent to other hospitals.

Cannon's researches have shown that in animals kept in a state of fear, anxiety, or anger, the suprarenal glands become more active, and the amount of adrenalin contained in the blood of the suprarenal vein increases. It is recognized that the thyroid gland reinforces the suprarenals. The enlargement or fulness of the thyroid in a certain number of these patients, and their resemblance to cases of Graves' disease, are accordingly of considerable interest. It must be confessed that such physiological tests as could be attempted did not show any participation of the suprarenals. Neither hyperglycæmia nor glycosuria could be demonstrated, observations on the blood pressure gave no abnormal results, and no definite reaction either on pupil or pulse followed the instillation into the eye of two drops of ordinary adrenalin solution. The only facts bearing on the action of the endocrine glands are the changes observed in the thyroid and the presence of exophthalmos, which occurred definitely in a certain number of exhausted soldiers, and after a period of two or three weeks disappeared.

Symptoms.

The various types seen were broadly classified into the following four main groups :—

(1) Simple exhaustion.
(2) Neurasthenia and anxiety.
(3) Hysterical states.

(4) Confusional states: (*a*) mildly confused, simple or hysterical; (*b*) severely confused, short and long types; and (*c*) miscellaneous groups of mental disorders.

Simple Exhaustion.—This condition, in itself non-morbid, was yet of extreme importance both from its frequency and from the point of view of the work which the centre was called upon to fulfil. As a working procedure it was found expedient for purposes of treatment to include the milder neurasthenic cases in this group.

Patients in the group would usually pass to the convalescent block on the third or fourth day after admission. For the first few days they were given a liberal diet, and allowed as much sleep, night or day, as they desired. Their treatment on transference to the convalescent block is described later on.

Neurasthenic Group.—Under this term are included those patients who presented anxiety and psychasthenic symptoms. The inadvisability of using the term " neurasthenia " for these cases of severe exhaustion in soldiers was always well realized. It was, however, the only " official " diagnosis available. The outstanding feature of the soldier's " nervous breakdown " was the rapid improvement which occurred under the simplest forms of treatment. It was therefore unfortunate that in a disorder in which it was of the utmost importance to avoid suggesting symptoms to the patient, it should have been the practice to use a diagnosis which immediately brought to his mind the intractable forms of the neurasthenia of civil life, In order to avoid this, Captain W. Johnson suggested in 1917 the use of the term " exhaustion syndrome," which he considered eminently suited to the soldier's condition.

The importance which an exhausted state possesses as a predisposing factor in the psycho-neuroses can scarcely be over-estimated. One of the chief functions of the N.Y.D.N. centre was to avoid suggesting symptoms to the patients who, being in an emotional condition, were extremely susceptible to develop neurasthenic, psychasthenic and hysterical traits. The majority of patients admitted for presumed nervous disorder were of this class. The patient possessed at the time of admission a low margin of self-control, and accordingly his degree of " suggestibility " was very high. A display of ignorant sympathy or an impressive medical examination would tend to produce or confirm all those symptoms which it was important to avoid. Once a man had received outside confirmation of his own introspective imaginings, a chronic state of neurasthenia was very apt to be induced.

On clinical examination the confirmed case revealed the association of definite physical signs with his various subjective symptoms. The latter were headache, dizziness, failing powers of concentration, inefficient memory for details, a sense of helplessness when faced with the necessity of making an effort, a constant state of irritability, and irregularity of sleep associated with nightmares or a riotous mental activity during the night. Behind all these, too, there existed a continual state of dread and anxiety. Of the objective signs the following were commonly found : tremor of hands and head, tachycardia, irregularity of the pulse, semi-dilatation of the pupils with diminished reflex excitability, definite increase in the tendon reflexes, some degree of cutaneous hyperæsthesia, more particularly of the soles of the feet, excessive tendency to sweating and vasomotor disturbance (chiefly evidenced by the presence of cold, damp, cyanosed hands), and occasionally a marked pilo-motor reflex. A recent loss of weight was fairly common also. The general physical standard of patients in this group was low. The "weedy" appearance which the majority presented on parade was very noticeable.

This group of cases comprised about 60 per cent. of the whole, and, in view of its importance from a medical aspect, demands more detailed consideration. Inasmuch as the symptoms and physical signs were most pronounced in a certain proportion of patients who exhibited exophthalmos, these will be taken as the type. It must, however, be remembered that whilst in the majority of cases in this group the symptoms and physical signs were usually present in a much less degree than described, a very definite clinical condition was recognizable as forming a basis for the whole group. And, indeed, the impression gained was that the cases with exophthalmos were merely the more striking example of what was essentially one symptom-complex. In the more marked instances exophthalmos was pronounced and the thyroid gland was definitely enlarged, but in the majority of patients there was no evidence of thyroid hyperplasia. The patient usually looked pale and haggard, and stated he had lost weight recently. The skin was moist, and often beaded with perspiration. The extremities as a rule were cold and cyanosed. Tremor was a constant phenomenon. It affected the hands and arms chiefly, and was rhythmical and fine in character. All movements were carried out in a quick excitable fashion, and any effort easily produced sweating and an undue sense of fatigue.

The condition of the heart described in connection with "effort syndrome" was found, the cardiac impulse being diffuse and heaving in character. In a few cases a well-marked soft systolic murmur was to be heard over the base of the heart when the patient was lying down. It disappeared on standing up or after two or three days' rest in bed. The pulse rate varied through a wide range in any one individual without appreciable cause. The rate which had been 80 or 90 in bed would become 120 or 130 when the patient had walked a little; and this condition still persisted at the end of three weeks. The accompanying chart shows this, as also the fact that at first the pulse rate in bed took a few days to settle down to an average of about 80, and then remained at that figure, while the "up" pulse rate kept a fairly constant level the whole time.

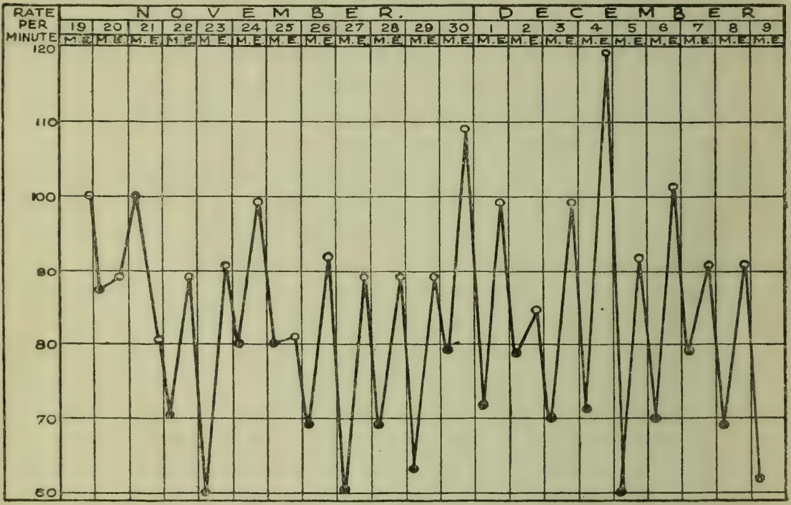

Chart II.—Showing morning pulse (●) taken in bed, and evening pulse (o) taken after the patient had been up a few hours. It illustrates the abnormal excitability of the pulse rate in these patients.

In the normal individual pressure on the eyeball retards the pulse rate six to ten beats per minute. In a few of these patients with exophthalmos an exaggeration of this reflex was found. Thus in one marked case the pulse rate fell from 130 to 90; in another the pulse became imperceptible; and in yet another the blood-pressure at the wrist seemed to decrease markedly and the rate fell from 120 to 100.

An abnormal condition of the vasomotor system was the rule. On parade a patient might exhibit pallor and sweating of the face, associated with a cold, moist, and dusky cyanotic condition of the hands. The same patient put to bed might present in a short time a flushed face, hands moist, warm, and reddish-purple in colour. In both states there appeared to be vasomotor stasis, as pressure with the finger easily emptied the vessels, and the colour took an abnormal time to return.

The nervous reflexes showed slight alteration. The pupils were usually slightly dilated, and gave a slow diminished reaction to light. The tendon reflexes were always exaggerated, and in a few cases unsustained patellar and ankle clonus were obtained. The pilo-motor reflex was more frequently absent than present. The line produced on the skin in performing this test was usually abnormally red and persistent.

The mental state was generally one of subdued excitement. The patient was worried and troubled, and possessed very little or no emotional control. Some had struggled to remain at duty and were ashamed of having broken down. A few had been sent to hospital as the result of being blown over by shell explosions, but the majority had broken down under the strain of heavy fighting. A serious result of this state of mental tension was excessive psychic irritability. A very slight disturbance or noise at night was sufficient to waken the patient, and once awake his mental activity banished all possibility of sleep. This irregularity in sleep had frequently lasted for weeks, and in this way had produced a marked exaggeration of the disordered state. The facial expression was one of fear and anxiety. In some the exophthalmos was so pronounced that the eyes seemed to be starting from the head, and the patient, when handed a looking-glass, has been astounded at his own appearance. As a rule, however, the amount of sclerotic visible round the corneal margin was small and the result was a definite staring expression. In all cases von Graefe's sign, lagging of the upper eyelids when the eye is made to follow a slow downward movement of the finger, was well marked. Joffrey's sign, absence of wrinkling of the forehead on looking up, was found in those cases in which exophthalmos was most pronounced.

The subjective symptoms varied widely. Usually the patient said he had become "nervous and weak," that he suffered from throbbing headaches, dizziness, palpitation, and precordial pains, more especially on exertion. Digestive discomfort and diarrhœa were complained of more rarely. A few had frequency of micturition. Sleep would be irregular and easily disturbed. Dreams, from which the patient would wake up in a profuse perspiration, were fairly common. The whole general state of the individual was one of querulousness and anxiety, the attitude of the man who feels that he cannot drive himself one step further.

It was found that after rest in bed with full diet, suitable tonics and occasionally Dover's powder at night, the condition of all patients rapidly improved in ten to fourteen days. At the end of that time the exophthalmos had greatly decreased, and in about half the cases had disappeared altogether. The pulse remained rapid and excitable, and the general subjective symptoms always appeared ready to manifest themselves if the patient experienced any excitement. A few who were observed for a month were still unfit for duty at the end of that time. The remainder were evacuated to the base after two or three weeks.

Hysterical Group.—This consisted principally of mutes and patients with coarse tremors; a much smaller proportion were patients with deafness, deaf-mutism, or trouble in walking. There were only two cases of hysterical blindness. Contractures and local palsies were seldom seen.

A troublesome complication, at first met with in the treatment of mutes, was an obstinate form of stammering. This is also a hysterical condition. Difficulty of enunciation with each and every word, or a milder form, in which speech was performed slowly in a monotone and with a markedly tremulous voice, was exhibited.

Belonging to this group are certain cases which, on admission, presented coarse clonic tremors, a kind of "shaking all over." This was usually the result of some severe fright, such as a heavy explosion near by, or of having been partially buried in debris. The condition is, in fact, one of the "manifestations of fear," and its perpetuation a hysterical phenomenon. These patients with severe hysterical tremor were excessively resistant to treatment. They lay in bed, apparently content to go on shaking, as long as they were allowed to do so. Most of them were emotional young individuals. A notable point was the extreme rarity with which commissioned and non-commissioned officers were affected. Altogether there were some fifty cases of the kind. In common with what is seen in other hysterical disorders, the patient's general state might improve all round, while his hysterical symptoms became worse. He might soon walk comparatively well, but the shaking of his head and shoulders seemed to become more hopeless each day. The movement chiefly affected the muscles of the neck, shoulder girdle, and pectoral regions. When the patient was lying undisturbed the shaking became less coarse, and it disappeared entirely during sleep. When the patient was awake it never entirely ceased, and any slight suspicion of danger might aggravate it to an extreme degree. These relapses, however, were fairly amenable to treatment.

Examination of the muscles affected brought out a few points of great importance. The patient gradually assumed a "fixed attitude," varying with the severity and distribution of the tremor. The head might be turned to one or other side, or bent backwards, and the shaking carried on from this position. The shoulders were slightly raised, and the movement of the points of the shoulders during the shaking was often considerable. The arms were flexed at the elbows and the hands in a position between pronation and supination; the tremor was a slight up-and-down movement of the forearm.

These positions, which have been referred to as "fixed attitudes," were the result of a state of mild tonic contraction of the muscles concerned. This condition was readily recognized on palpation with the hand, especially in parts, such as the neck and forearm, which can be loosely grasped. This tonic condition of the muscles tended to diminish during the first three or four days, giving place to an increased coarseness in the tremor. It may be of interest to note that a normal individual is able to assume voluntarily this tonic state, but finds more difficulty in performing for even a short time the extensive coarse movement which these patients were able to keep up continually.

The head, shoulder and arm movements formed the common type. In a few cases these ceased rapidly and left an irregular movement of the facial muscles, chiefly of the orbicular muscles of the eyelids and mouth, associated with slight head tremor. In one case the movement became localized to the left platysma, the whole of which could be plainly seen contracting beneath the skin; this patient had had a slight twitching in this position years before. He improved under treatment, but relapsed badly after a fright.

The relative proportion of hysterical conditions to others among the 5,000 admissions to the No. 62 Casualty Clearing Station N.Y.D.N. Centre during the three months of the battles of Ypres in 1917 is shown by the following analysis.

The hysterical patients formed approximately 10 per cent. of the total, and the majority came from the group classified as "shell shock, wounded."

TABLE VI.

Classification of Cases with Hysterical Symptoms, August–October, 1917.

Hysterical Symptom.	Number of Cases.	Proportion to the Total Admissions.
1. Mutism	200	4·0 per cent.
2. Deaf-mutism	30	0·6 ,,
3. Disorders of locomotion ..	30	0·6 ,,
4. Coarse tremors—		
(*a*) severe	30	0·6 ,,
(*b*) mild	120	2·4 ,,
5. Deafness*	100	2·0 ,,
6. Blindness	2	—
Total hysterical cases treated	512	10·2 per cent.

* These cases of deafness were not entirely hysterical. In over 70 patients some slight lesion of the tympanic membrane, or a partially recovered old ear trouble, was found, *i.e.*, a slight organic basis was present.

A similar analysis of the cases admitted during the subsequent thirteen months showed only slight variations from the above relative proportions.

Owing to the military situation, records for the working out of a classification table of the cases with hysterical symptoms for the whole of the thirteen months from October 1917 to November 1918 are not available, but it was possible to form such a table for the last eight months of the period. During these eight months 1,820 patients were admitted. The proportion with hysterical symptoms proved to be almost identical with the analysis given in the above table, except that the cases of severe tremor were slightly more and cases with hysterical walk slightly less numerous.

Confusional States.—The occurrence of a confused condition, lasting four or five days, was much more common in the early stages of the psycho-neuroses than is generally realized. A recovery in two or three weeks from this short period of confusion was the rule. It became important in the N.Y.D.N. centre to recognize this, in order to prevent evacuating such cases to the base as mental cases, where on arrival nothing beyond a history of a few days' mild confusion would be discoverable. Apart from other considerations, the admission of these patients into mental hospitals has in certain instances been harmful to the ultimate progress of the case, through the patient getting the idea that he might become insane. On an average, out of some thousands of soldiers admitted to the N.Y.D.N. centre, about 10 per cent. showed definite evidence of confusion.

The immediate or exciting cause might be purely psychic, or might have in it a physical element. Out of some hundreds of cases it was found that 40 per cent. had been in the immediate vicinity of shell explosions, and might therefore be suspected of having undergone slight concussion. Clinical evidence on this question of "commotional" or "emotional" causation was, however, very unreliable. Thus a patient might be admitted in an irritable apathetic state, with unequal pupils or complaining of headache, and with a pulse-rate of 60—suggesting concussion—where enquiry showed that the man was the subject of a purely emotional breakdown. An examination of the tympanic membranes and the discovery of a recent rupture were occasionally valuable aids in the diagnosis of concussion.

In a certain proportion of cases the two factors, the psychic and the physical, were no doubt operative in the same patient, and no accuracy should be claimed in separating the two. On the whole it seemed that of patients showing confused states certainly not more than 10 per cent. had suffered from any physical concussion, while the remainder were suffering entirely from emotional influences.

In those cases which were due to actual concussion, a noticeable feature was the relative freedom from subsequent subjective troubles as compared with those which were due to emotional disturbance. In about three-fourths of the cases the confusion was of short duration, lasting twelve to twenty-four hours, and was simple and transient in character. The notes of the cases describe them in such phrases as the following: "appears dazed," "looks strange," "is inclined to behave foolishly," "is dull and takes no interest in anything," "does not appear to understand questions," and so on. This type of case may be classified as the mildly confused group. The remainder of the cases presented quite distinctive features, and may be classified as the severely confused group.

The essential points about the cases falling into the mildly confused group were, as already mentioned, the shortness and mildness of the confusional state and the rapid recovery which characterized them.

In the simple type, cases which, for want of a better term, were afterwards diagnosed as "neurasthenia" frequently presented an initial stage of slight confusion. They carried out simple commands, such as putting out the tongue, and after an unduly long latent period would answer a few simple questions, such as name, age, and so on. They, however, failed completely when questions were persisted in, and were quite unable to give a connected account of themselves. They might have no knowledge of what had happened to them in the line or of their journey down to the casualty clearing station. They might supply here and there an incident, but links were wanting in the chain of events. The commonest form of amnesia was that in which the patient would recall events in the line until a certain thing happened, and then his memory became a blank. Usually he "came to himself" in the ambulance car a few hours later. Less frequently the amnesic period was more extensive, and the patient would be unable to recall events which had immediately preceded his breakdown. It was, however, very rare indeed to find a case where the amnesia extended into pre-war days or home life. The following case is an example of the simple type :—

The patient, aged about 25 years, of good physical development and appearance, was admitted in an excited and confused state. He recognized no one round him, and did not know where he was. With some difficulty he was induced to give his name. He kept looking anxiously about the ward and asking "Where am I ?" He was continually getting out of bed, but when spoken to he would return quietly. Altogether he was very irritable and troublesome. After his first night's sleep he woke almost completely recovered, and only complained of headache. His statement then was : "I was assisting Lieutenant —— in looking after some wounded. We had several bombardments. I went outside the dug-out for fresh air, and I remember climbing the steps to get out. The next thing I knew I found myself in bed, and wondered why they would not give me my clothes."

This patient had been in France only a few months. Apparently the sight of several wounded men had affected him deeply. Two days after admission he was doing useful work in the ward. At no time, whilst he was under observation, did the physical signs show any definite variation from the normal, and in fact after the first few days nothing objective or subjective remained to indicate that he had passed through a period of confusion.

A fairly characteristic form of mild confusion was associated frequently with hysteria and could be observed in the earliest stages, before any definite hysterical manifestation had become established. The hysterical manifestation is, after all, only the expression and not the substance of hysteria, which is constituted by the abnormal mental attitude of the patient.

Seen in the earliest phase, the patient usually lay quietly in bed with his head under the clothes. His desire was to be undisturbed and hidden, and if interfered with he was inclined to be resentful, and would sit up glaring about. Repeated efforts were necessary to induce him to perform simple movements such as closing his eyes. He gave the impression of having understood what was asked of him, but refusing to carry out the action. When eventually he would obey, his actions were incorrect. Instead of closing his eyes, he would blink spasmodically or put his face through a series of contortions. Frequently he would break off in the middle of his movements, lie down in bed and abruptly turn his back. As a rule, a single night's rest was sufficient to bring this attitude to an end, and the patient then became of the ordinary hysterical type, presenting mutism, coarse tremor, paresis or paraplegia, as the case might be.

Less frequently the confused state was somewhat deeper, and the patient appeared not to understand anything said to him. The result of being disturbed was to cause him to shriek out, and to produce a severe outbreak of emotionalism, such as passionate weeping, which was often associated with the revival in his mind of some harrowing experience. Such cases usually took four or five days before anything approaching normal emotional control was regained, and later proved themselves to be exceptionally emotional individuals by nature.

In the severely confused group the confused state was profound, and usually persisted for from three to ten days. For these patients a special mental ward was provided, and during the whole time the No. 62 Casualty Clearing Station N.Y.D.N. Centre was open this ward was invariably in occupation. The vast majority of patients who were admitted in a confused condition had usually gone through some emotional experience of appalling severity and horror. The poignant character of the ordeal rather than any inherent weakness in the individual was the overwhelming factor in the causation of this condition, although prolonged exposure to the conditions of trench life, together perhaps with an illness of a toxic nature, might have prepared the ground for what was ultimately produced by an exciting emotional cause of great intensity. In a certain number where this history was not obtained, and the soldier had only served for a few months, it was found either that a previous breakdown had occurred in civil life, or that the patient was young and of such a type temperamentally that he obviously would not endure the conditions in the fighting area for long. In many cases, too, reports were received stating that a change had been noticed in the man's behaviour with his unit for some time previously, that he had become unreliable at his duty, sometimes irritable, and at other times depressed and gloomy. As a rule he had been restless and unable to sleep whilst in the line, frequently parading sick with a complaint of severe headache. On examination the general appearance was one of exhaustion, the patient usually being in poor physical condition. There was fine tremor of the hands, overaction of facial expression, a state of general sweating, rapid pulse (100–120), exaggerated tendon reflexes, cutaneous hyperæsthesia and an irritable reaction of the pupils to light.

Occasionally an opposite condition was observed; the tendon-jerks were diminished, cutaneous sensation dulled, and the pupillary reaction to light slowed. This usually indicated that the state of confusion had already lasted several days. The urine was examined in many cases, but neither sugar nor albumen was found present.

A number of these cases may be described as of the shorter type. Such cases, on account of their transient character, might appropriately be termed cases of " exhaustion psychosis." They, however, exhibited an acute confusional state of a more profound nature than those described under the mildly confused group, their confusional state lasting three, four, or even five days. When seen within a few hours of the onset, a patient of this type was wildly excited and would not remain in bed. He kept up a constant low muttering, snatches of which were intelligible and were found to refer to his later experiences in the line. He would occasionally shout out loudly and tremble with terror or burst into tears. No coherent answer could be obtained to questions, although his attention might be gained sufficiently at times to obtain some form of reply. He did not recognize the fact that he was in a medical unit, nor did he appreciate his surroundings or recognize those around him. He appeared to be living again through his recent experiences in the line, and interpreted anything occurring near him from this point of view. Those next him he thought were comrades in his unit, whom he addressed by name and talked to continually; or they were Germans, snipers, and so on. Frequently he would sit up suddenly in bed and, with a terrified look on his face, shout " Look, look ! " after which he would sink back in bed moaning a friend's name. Any noise occurring near was thought to be from bombs, shells, machine guns or other weapons, and was liable to bring on one of these brief outbursts.

Towards the third or fourth day the patient's state of confusion markedly decreased. He could then give some account of himself, his unit, and of what happened to him in the line. There was frequently, however, a complete blank in his memory which might be partially filled later, but in not a few cases certain recent episodes were permanently forgotten. At the end of ten days or so he would have improved so much that constant supervision on account of the "wandering tendency" was no longer necessary, and towards the end of the third week there would appear to be very little wrong with him. He might then complain of headaches, dizziness, palpitation, irritability, a sense of undue fatigue, nightmares or irregular sleep. Many tended to worry over their past amnesic state, or had a dread of mental disorder. At this stage patients were evacuated to the base, and their subsequent history was not ascertained. The following is an example of this type of case :—

The patient was 19 years of age and boyish in appearance. The notes received from the medical officer of his unit stated : "He was sent to the regimental aid post for his strange behaviour. At first he answered questions by nodding or shaking his head. When given food he crumpled it up and dropped it on the floor, and when given a jug of water he poured it over himself. He is very restless, and will not sit in one place for more than a few minutes, then gets up and wanders round in a half-dressed condition. Temperature is normal. Pulse 120, and tendon-jerks are exaggerated." When he came under observation in the N.Y.D.N. centre a few hours later he was highly excited and deeply confused. He had no idea where he was, and it was impossible to get any information from him. He was continually trying to get out of bed. A little later he became very emotional, weeping and shouting aloud, repeating anything he heard said. He was continually spitting about the floor. Next day he supplied one or two details about his home in Bradford, but could give no account of his recent experiences. Careful watch was still necessary to keep him in bed. He slept indifferently for the first three nights, but after that obtained almost twenty-four hours' continuous sleep. On the fifth day he was quite quiet and talking reasonably. Appetite good, pulse 96. When evacuated to the base he was still inclined to be emotional and somewhat irresponsible in manner.

In the longer type of cases the depth and duration of the confusion seemed to warrant their being grouped under the term "acute confusional insanity." At the end of two or three weeks patients of this class would still show signs of confusion, persistent hallucinations, ideas of persecution and other symptoms. They had accordingly to be evacuated to the base as mental cases.

On admission the patient was usually in such a wildly excited condition that he required tying into bed. He would continue to struggle and shout sometimes for two or three days. He was, as a rule, suspicious and presented a dangerous demeanour. His mind would be full of some real or supposed injury to himself. He would take no notice of questions, and his talk was all concerning the subject on his mind, *e.g.*, " You are the one " ; " You are a German in disguise " ; " Will they shoot me ? " He would hear voices outside, and shout that everyone was plotting against him.

Another patient would believe that the ward was an entrenched position, would picture machine guns here and there, and chatter about the fighting, calling out orders in a firm voice. The violent acute stage usually terminated towards the end of a week, leaving the patient in a somewhat apathetic condition, in which he lay in bed muttering to himself. His hallucinations and false ideas would still, however, be active, and frequently there was a brief recurrence of the excited state, followed by a temporary relapse to marked confusion.

At the end of three weeks the patient usually presented a slow manner and a gloomy demeanour, with a marked tendency to be secretive and suspicious. When evacuated to the base in this condition many cases were definitely delusional. The following is a typical example :—

The man was aged about 21 years, and of average physical development. The notes stated : " This soldier was admitted to field ambulance in a restless and excited condition. His temperature was 99·4°. Next morning he appeared to be very nervous, and told a long story about getting married. Three days later he suddenly began to be troublesome, and was continually wandering away from the ward. On the fifth day he was more excited, and stated that the ward orderly was impersonating him and that his father was outside waiting for him. The slightest noise made him start and look about in a terrified manner. On another occasion he shouted out that he was Captain ——, and threatened to put certain persons under arrest. He was, however, never quite unmanageable."

On the tenth day he came under observation at the N.Y.D.N. Centre. He was in a very terrified state of mind. His expression was staring and anxious. He talked rubbish in reply to questions. When left alone he would lie for hours with his head covered up, muttering to himself. There was a slight general tremor of arms and legs. Restlessness was marked, and great difficulty was experienced in keeping him in bed.

On the fourteenth day his condition had become much quieter. He still wanted " to get on with his journey to Deal," and required careful watching. Occasionally he had brief attacks of weeping, following which he would suddenly become quite cheerful and talkative. His appetite was variable ; he slept lightly and woke up frequently.

On the eighteenth day his condition was thus noted : " Complains of headaches ; his attention is very poor, his cerebration much slowed, and he still exhibits terror, both in appearance and behaviour. He stutters occasionally, and is constantly asking to ' be allowed to go.' " The hands showed a fine tremor. Pulse 120. Tendon-jerks much exaggerated. Pupils equal, and reacted sluggishly to light and accommodation. A few days later he managed to get away, and walked up to a post quite near the line. After being returned to the casualty clearing station he continued to act in an irresponsible manner until he was eventually evacuated to the base.

Miscellaneous Group.—A few patients were admitted with varying degrees of confusion, in which eventually a diagnosis of definite mental disorder was established. Such conditions were mental deficiency, dementia, general paralysis of the insane, acute mania, maniaco-depressive insanity, delusional insanity and melancholia. One or two cases of dementia præcox and paranoia were also observed.

Three cases of an uncommon form of mental torpor were observed. At first they were regarded as being either hysterical or malingering, but close observation over a prolonged period sufficed to exclude both these conditions. They lay in an apathetic state in bed, with apparently complete suspension of all psychic functions. Deprivation of meals produced no reaction. They took food, however, in the ordinary way. There was no incontinence of urine and fæces. When spoken to they evinced no interest and either gave no answer at all, or muttered, "I don't know." Physical examination showed no noteworthy change from the normal state. The following are the notes of one of these cases.

The patient was 23 years of age, and stolid and robust in appearance. On admission he presented a dazed, lethargic condition. He lay in bed with his face pressed against the pillow, and rarely changed position. If rolled on to his back he lay with his eyes closed and made no resistance. After much persuasion he opened his eyes and glared round, with apparently no evidence of recognition in his expression. All questions and the ordinary means of rousing (shaking, etc.) produced no result. After four or five days, during which he had lain most of the time like a log, he began to look round a little. When asked how he felt, he stared hard for several seconds, and then answered, in a low tone, "I feel better." He volunteered no conversation himself, accepted passively anything which happened, and had not appreciated that he was in hospital.

After eleven days he began to walk aimlessly up and down the ward, but took no notice of other patients, and never spoke to anyone. He was put for a few days on a pure milk diet, but this called forth no protest. After taking him to a concert, in hope of rousing him, practically no change occurred in his condition.

On the seventeenth day his condition was thus noted: "Strong frowning expression, which is persistent. Slight twitching movements of the orbiculares palpebrarum. Tongue tremulous. Attention is only obtained with the greatest difficulty, and goes again at once. He answers simple questions after a delay of several seconds. During the whole time he has been in the ward he has made no complaint of any kind, and no account of his history, recent or remote, has been obtained from him. His habitual attitude now is to sit with his head buried between his hands. Physical signs of the nervous system show no evidence of organic disorder."

He was evacuated to the base during the fourth week of this condition. In another similar patient no improvement had occurred at the end of six weeks.

This frequency of confusional states in the earliest stage of the psycho-neuroses provides a lesson for all who may in the future find themselves engaged in the treatment of men who have suffered from nervous disorders during the war. It throws light on symptoms which otherwise appear unaccountable, and helps to explain the mental instability which many patients continue to show in an obstinate degree. Prognosis and treatment in such cases will be unsatisfactory unless the possibility of there having been in many instances this initial state of confusion is kept in mind.

Treatment.

The treatment of the group headed exhaustion was, as above stated, confined to rest and good feeding. That of patients in the neurasthenic and anxiety group resolved itself into a longer rest in bed, symptomatic treatment, and the exercise of simple forms of psycho-therapy. Following his transference from the admission block, the man would be kept a further seven to ten days in bed. Psychic and medical treatment would be given for his several subjective ills, which were chiefly digestive disturbances, headache and irregular sleep. A regular small dose of bromide did not appear of any decided benefit, and its use was soon discontinued. A large dose occasionally at night, however, was frequently beneficial.

Nightmares were neither as common nor as intractable as they appeared to be among the cases described in England. Hypnotism was a simple and efficacious means of providing sleep. Psycho-analysis might be indicated in the most obstinate cases, but when once the patient's confidence was gained an intimate talk would go a long way towards helping a man back to his state of self-command. In many cases fear played the dominant part. The patient was fearful about everything, chiefly as to whether he would ever completely recover, whether he was regarded as a shirker, and above all, whether he would ever be sent to face the line again. He was intensely introspective, and was full of complaints to an almost nauseating degree.

In the vast majority of the milder states reliance was placed on the provision of new interests and occupations, in sufficient degree to replace the memory of recent experiences, rather than on the opposite course of reviving and analysing a patient's experiences in the line. It is from this neurasthenic group of cases that half the patients evacuated to the base were drawn.

In the treatment of the hysterical group, each case after transference to the special hysterical ward, was thoroughly examined, and after organic disease had been excluded the patient would be told his " cure " would take place at such a time on a certain day. In the interval thus elapsing before active treatment was attempted—usually three to four days—the soldier was exposed to the " atmosphere of cure " which was maintained in the ward, and would see recovery occurring in patients around him. Not infrequently the disappearance of the hysterical manifestation was induced during this interval by the sister of the ward if she had prolonged experience of this difficult type of case. Occasionally, too, spontaneous recoveries occurred.

The actual cure of each patient was carried out in a separate hut which was fitted up as an electrical and medical room. Here the medical officer and his patient remained closeted until recovery was complete. As regards the methods employed, the intensity of treatment naturally varied with the individuality of the patient, his previous history, and so on. In all methods treatment was by suggestion. It was invariably commenced by explaining the nature of the condition to the man and assuring him of the complete absence of organic injury to his nervous system. The methods of suggestion employed were based on Babinski's teaching. Here the personality of the medical officer is always of greater importance than the particular method. The more convincing the medical officer, the less often should he have to resort to such devices for reinforcing his suggestion as the practice of light hypnosis, or the application of mild currents of faradism. Still less should the violent methods be employed which were at one time recommended in Germany. If the patient's confidence had been obtained, it was possible to dissipate his hysterical manifestation without laying a finger on him. For complete treatment, the strong " suggestion " of recovery must merge into persuasion, and this finally into methods of re-education, which must include psychic as well as physical measures.

As long as hypnotism is regarded as a mystic rite by the patients, so long will it be contra-indicated in the treatment of hysteria. Psychotherapy, too, is essentially a mode of treatment which, if it is to secure lasting benefit, must be explicable in simple terms to the patient, and not in any way an enigma.

A troublesome complication of hysterical mutism was the onset of stammering when the voice was restored. It was found to be obstinate and difficult of cure. Much time was at first spent in devising treatment for this, and good results were only obtained at the expense of very much trouble and patience. Soon it was discovered that the best time to prevent this complication was at the sitting when the patient's voice had been restored. By establishing the working rule that speech re-education was immediately to succeed the recovery of the voice, subsequent stammering was largely avoided. Similarly, careful re-education was of the greatest importance in the successful treatment of all other hysterical disorders, more especially those of locomotion.

In a few cases which were treated by suggestion, particularly hysterical arm and leg conditions, the removal of the hysterical symptoms revealed the presence of a slight organic basis.

Where hysterical symptoms were found associated with a jaded, war-weary state, a modified form of Weir-Mitchell treatment was very successful. However irksome this might appear to the patient at the time, it had to be remembered that failure to improve him early left only one alternative, a gradual drifting into that state of almost hopeless chronicity, the " nervous wreck."

In the cases marked by tremors special measures were needed. In the first few days, before the general shaky condition settled down into the definite coarse hysterical tremor, the patient was kept in bed, fed fairly generously, and, purgatives excepted, no drugs were given. On the second or third night a mild hypnotic might be called for if the patient exhibited insomnia, but this was seldom needed. The change from trench life to a comfortable bed was usually sufficient to induce sleep. More important than drugs at this stage was psychic treatment. The patient found himself in a ward where the atmosphere of cure was strong. He saw other men rapidly recovering from conditions similar to his own. It was found that the least hysterical type of patient was able voluntarily to relax his muscles more or less completely. He was told to let himself go " as though he were dead," and, if this was done with any success, it was then demonstrated to him that his limbs could be " flopped " about and that at the same time his tremor practically disappeared. This mild exhibition of suggestion was found of great value. On the fourth or fifth day he got out of bed and entered on a course of mild graduated physical exercises under a special instructor.

Once the typical uncontrollable tremor had been thoroughly established, rigid intensive treatment alone gave good results. Psychic treatment again played the greater part, and most of the procedure which followed was of this nature. Each case was placed in a cubicle, the lines of treatment explained to him, and his co-operation enlisted. He was kept lying down in as relaxed a position as he could assume, although as a rule he did not succeed too well in this. He was seen daily and his efforts commended. The diet was light and given at stated intervals. A mixture containing valerian was administered night and morning, or, where indicated, iron and arsenic. Active local treatment of the muscles involved was given twice daily and consisted in five minutes' rubbing, followed by five minutes' exercises. Odorous liniments were more successful than the inodorous. The rubbing was done by a professional rubber who was accustomed to train men for athletics, and whose methods accordingly were singularly applicable to this type of case. The exercises to follow this were valueless unless the fixed attitude of the patient was forcibly corrected whilst they were being carried out. For instance, where the tremor was one in which the shoulders were fixed in the shrugged position, this was corrected either by an assistant, or better still by the patient grasping the seat of his chair firmly and forcibly dragging his shoulders down. In this position the patient was instructed to perform strong head turning, bending and rolling movements in regular sequence.

Suitable exercises and suitable positions in which they were to be performed had to be devised for each individual case. If the shoulders were carried forward, as in marked pectoral tremor, a long stick under the arms served to restore their position. If there was a wrong position of the head, this could be counteracted by an assistant pulling the head in a diametrically opposite direction. The resistance experienced in counteracting these attitudes was found to diminish on each occasion of the treatment.

As an adjunct in aiding a patient to correct his fixed attitude a mirror might be placed in front of him. By this means visual reinforcement was supplied to the voluntary effort, which, as is well known, is deficient in these cases. A looking-glass, too, was found essential for the performance of the facial exercises in face tremor.

Finally, patients were never allowed to lose heart during their treatment. A slight modification in routine might be found to suit the mental peculiarity of a particular patient, and this short road to recovery was always kept in mind. If treated from the commencement little trouble was to be anticipated. The average time in the cubicle was ten to fourteen days. In one or two instances, where the desire for recovery had not been the most prominent point in the case (*les malades invetérés* of the French), treatment had to be extended up to three weeks and then suddenly the malady vanished. Here there must be no misplaced sympathy ; the treatment should consist, in the aphorism of Sir George Savage, of "sympathetic but judicious neglect."

In patients presenting the simple type of acute confusion it was not always necessary to give a sleeping draught as a routine measure. If, however, after the first two or three hours the excitement and restlessness showed no signs of abating a full dose was given. As a rule the majority of cases settled down rapidly when given absolute quiet in bed and appropriate feeding. Early movement of the bowels should be procured. It was found of importance that these patients should be disturbed and questioned as little as possible. Tactless examination, apart from increasing the state of excitement, might tend to focus the patient's attention on his loss of memory or on his late experiences, and convalescence might in this way be adversely affected. After twenty-four hours' absolute rest most patients were able to volunteer a fairly complete account of themselves. Many cases subsequently complained of various subjective symptoms, chiefly headache, buzzing sensations in the head, disordered sleep, a feeling of bodily fatigue and a marked tendency to emotionalism. Frequently the patient presented a fine tremor of the hands and an excitable pulse. These formed the basis for the diagnosis of "neurasthenia" which sooner or later was usually applied to the subjects of mild confusional attacks. Further it should be noted that owing to the mildness of this subsequent neurasthenic condition a patient was liable to meet with scant sympathy and might be returned prematurely to duty.

The treatment of these patients in the later stage in No. 62 Casualty Clearing Station was by graduated physical exercises carried out twice a day usually for two or three weeks ; and following this by sending the patient for one month's duty on agricultural or other work in a back area before he rejoined his unit. On an average, therefore, this procedure ensured that a patient who suffered from this simple form of confusion obtained six or seven weeks in which to convalesce. During the latter half of the time he was occupied in doing useful work in the army area and was away from a hospital atmosphere.

The following case serves as an example of recovery in a case of this kind.

' The patient, aged about 27 years, was a man with very inferior physique. He lay in bed with his head under the blankets. When his head was uncovered, his gaze became fixed and he had the appearance of witnessing some terrifying spectacle. This lasted for a few minutes, and he then broke into loud weeping.

He appreciated questions only when they were shouted loudly. He could not speak, sit up, nor walk. When placed on his feet he collapsed limply, rolled on the ground, and then assumed a position of opisthotonos. On relaxation occurring, a mere touch was sufficient to reproduce this state of opisthotonos. Repeated attempts were necessary before his attention could be secured, and he soon relapsed again into his state of fixed staring. Gradually his attention was obtained for longer and longer periods, during which his mutism and paraplegia were treated stage by stage. He returned to the ward able both to speak and to walk.

The above case illustrates the wisdom of allowing a patient time to recover from a confused state, however slight this may be, before undertaking the cure of his hysterical symptoms. In such cases a delay of three or four days with the patient in a suitable "ward atmosphere" should invariably be made. There is then no danger of provoking an emotional outburst during treatment, and hysterical manifestations can be dispelled with much greater ease.

A case of severe confusion must be kept in bed as long as there are any traces of confusion. Forcible means must be used, whenever necessary, to keep him quiet. Regular feeding, free movement of the bowels, and the early securing of sleep by every means possible, should be ensured. Putting the patient in a separate tent away from all other patients is advisable if this can be done. In the first few days immersion in a bath at a temperature of 103° to 105° F. for half an hour daily, or every twelve hours if necessary, followed by the administration of chloral hydrate and potassium bromide, or paraldehyde or veronal, has been a useful routine measure for quieting the excitement and inducing sleep. Whilst in the bath the patient's pulse should be watched. As a rule it has seldom been necessary to administer hyoscine hydrobromide, and all soporific drugs are withheld as soon as the patient's state permits. Hot wet packs have not proved as beneficial as the immersion of the patient in a hot bath. Much difficulty was experienced in feeding the cases in this group. They took little or no interest in their food, or refused it altogether. On the second or third day, therefore, forcible feeding was not infrequently required. Alcohol should be absolutely avoided. It is possible that in some cases the confusional state had been accentuated by its use. In one case an acutely delirious condition followed shortly after the patient had been given "a stiff whisky administered in order to pull him together." This man was very violent on admission.

In the last stages, when the confusion is passing off, a dose of potassium bromide occasionally at night has been sufficiently effective in treating the minor sleep troubles.

Diagnosis.

Malingering.—True malingering was very rare and could only be definitely proved in very few cases. Such cases were those in which one man feigned absolute deaf-mutism, another total blindness with a form of insanity, and one or two others complete loss of memory. The subsequent history left no doubt as to the diagnosis. In other cases where suspicions of malingering had been aroused, careful examination and observation would reveal the presence of mild symptoms which at once ruled malingering out of court. The man might become confused under examination or show complete lack of emotional control and the presence of a highly hysterical temperament, or he might have marked signs of exhaustion. These cases may be considered as coming under the heading " marked exaggeration of symptoms." Many wrongly regarded this as malingering, an opinion which it would be quite impossible to maintain on cross-examination in a court of law. In all cases where genuine symptoms are present to form a basis for the condition, it is impossible to indicate precisely where exaggeration begins or ends.

Desertions.—A slightly confused individual, or a patient with severe anxiety neurosis, or even a dispirited, exhausted soldier may fail to meet the demands of military discipline, and in this way bring himself into a position of the utmost seriousness. In marked cases of nervous disorders there was no difficulty in certifying such men—accused of cowardice, desertion, etc.—as " sick," and admitting them to hospital. Where, however, a man in a slightly neurasthenic state finds himself under arrest for a serious charge, the case becomes one of great difficulty. The Army order was that " when a man accused of desertion, etc., pleaded that he was suffering or had suffered from shell shock, he was to be admitted to the special army N.Y.D.N. centre for a period of observation."

In all, during the sixteen months, among 8,000 cases in No. 62 Casualty Clearing Station, about 70 such doubtful cases came under observation. It was the invariable rule to keep each man for a period of at least four weeks, and longer if necessary, during which time he was seen and conversed with once or twice every day. His medical and military history was carefully taken, and he was medically examined on three or four separate occasions. In this way it was possible to obtain a thorough knowledge of the patient. In addition, specially selected orderlies gave brief night and day reports on these cases. In the end the result of these observations and examination was embodied in a special report which was sent to army headquarters, and this was used eventually at the man's court-martial.

Official figures which have been published show that only 11 per cent. of the men on whom the death sentence was passed actually suffered the penalty, and this proportion is justified as a result of medical experience. The remainder were almost entirely cases of chronic and acute nerve exhaustion with a history of war sickness and wounds, who had suffered from a complete breakdown at the time of their action. A few were genuine "fugues" who had wandered away in a dazed conditon. Only a few of the cases of desertion were caused by mental deficiency, minor epilepsy, delusional insanity and dementia.

Prognosis.

In dealing with the question of disposal of the patients, the two periods must be considered separately.

During the first three months, namely, August, September and October 1917, when 5,000 cases were admitted and disposed of, the more forward medical units were overcrowded and an undue number of simple exhaustion cases was evacuated to the N.Y.D.N. centre. Accordingly the statistics show a relatively small percentage of patients—16 per cent.—as having been evacuated to the base. The remainder were kept in the army area, 55 per cent. returning direct to their units for duty and 29 per cent. being disposed of under a scheme which had been arranged with the army agricultural officer. Under this scheme suitable cases were sent to the latter officer to be allocated to various farms for one month's agricultural labour, at the end of which time they automatically returned to duty with their units. Cases which were so treated were the average neurasthenic patients, who would otherwise have needed evacuation to the base. This scheme proved of the greatest use. It provided, as it were, a probationary period of one month in which it became possible to see how a doubtful case was going to develop. A sergeant of the Royal Army Medical Corps was detailed to supervise these men, and he reported cases where improvement seemed incomplete and the men were not in a fit condition to return to duty. Of the 16 per cent. evacuated to the base, 4 per cent. were cases of medical or organic disease admitted in error to the N.Y.D.N. centre. The remaining 12 per cent. were cases with purely psycho-neurotic symptoms (8 per cent.), and cases of psycho-neurosis with medical complications (4 per cent.).

During the subsequent thirteen months fewer simple exhaustion cases were admitted, with the result that the statistics of disposal varied somewhat from those of the previous period. The total number of cases admitted in this second period was close on 3,000. Of this total, 44 per cent. were evacuated to the base, and the remaining 56 per cent. remained in the army area. Of the latter, a majority were given a month's farm work before rejoining their units. Of the 44 per cent. evacuated to the base, many were, as before, cases of other diseases. Only about 30 per cent. were cases of psycho-neurosis. Even of these latter a large proportion was evacuated to the base more in order to prevent overcrowding in the centre than for medical reasons.

Taking both periods, therefore, it will be seen that the majority of the cases admitted, after spending perhaps two to three weeks in hospital, either went direct to duty or else did one month's useful duty in the army area before rejoining their units. Such a procedure has been the best whenever it was possible to carry it out. In this way the soldier was never allowed to reach the hopelessly neurasthenic state which was so liable to be produced by moving him from hospital to hospital. It was found in fact that few of the soldiers evacuated to England with these conditions ever braced themselves up to fighting pitch again, although very often the question of accommodation at the base, and not the patient's medical condition, was the actual cause of the transference to England. It is even open to question whether such freak cases as at one time were continually being reported from England should not be regarded as artifacts produced by " unsuitable medical atmospheres." From this point of view a number of men who, after repeated trials, had been returned from the line as useless were purposely kept for several weeks under observation at the N.Y.D.N. centre. With the exception of a few mental cases, there was scarcely one man amongst these who, after the lapse of seven or eight weeks, was not suitable for discharge from the army direct to civil occupation.

It must be noted, however, that under the conditions existing in the forward area it was never possible at any time to be sure that on the one hand only entirely suitable cases were being returned to duty, and on the other that all cases sent to the base were the most necessitous. It was inevitable that mistakes should be made either way, but experience went to show that in a really questionable case actual life in the fighting line was the only criterion as to how a man's condition was going to develop. The cases in which self-control was recovered were the more numerous; and even apparently hopeless individuals recovered control in a surprising fashion and "made good." One such instance was that of a sergeant in a field ambulance, who did well for the first few weeks on the Somme in 1916, but then broke down completely and became untrustworthy under fire. For eighteen months he remained in this state, and then in March 1918 and afterwards worked assiduously and efficiently with the bearer division and was decorated for conspicuous gallantry.

Nothing could exemplify the difficulty of classifying cases better than such an example. Considering the difficulties, and judging by the reports supplied by the various centres, it seemed that this question of returning men to duty was dealt with in a just and conscientious manner. It was only by dint of hard-earned experience that the medical officer could attain any measure of success in judging his cases.

When discussing the proportion of cases returned to duty from a forward centre, the question has been often asked, "What was the frequency of relapse amongst such men?" Unfortunately, owing to the free movement of divisions from one army to another in accordance with varying military requirements, it was not possible to answer this with any accuracy. There was an impression that such patients only drifted from one hospital to another, and in order to throw some light on this a record was kept of the number of readmissions into the N.Y.D.N. centre of No. 62 Casualty Clearing Station during August, September and October 1917. Out of some four thousand patients returned to duty during these three months, less than one hundred were readmitted to this centre. It may be answered that possibly many more, after their division had been moved to another army area, would seek admission to other centres. To explore the question from this point of view, Lieut.-Colonel Gordon Holmes made the circuit of three army N.Y.D.N. centres and examined all the cases they contained. The result of his investigations was as follows:—

Total number of cases seen	573		
All recurrent cases..	57	= 10	per cent.
Cases with two or more recurrences ..	15	= 2·8	,,

He remarks that "consequently less than 3 per cent. were men who had passed repeatedly from the base to the forward areas. Nine of these fifteen cases had been treated in the

United Kingdom for previous attacks ; thus in only six cases out of 573 were the medical arrangements in France responsible for the return to the front line of men who were possibly temperamentally unfit."

These investigations definitely show that the occurrence of relapses amongst patients who were treated in France was never a very serious problem.

As regards recurrence in the various types, it was found that the majority of the relapses occurred amongst the neurasthenic class. Patients with hysterical symptoms, once the nature of their condition had been explained to them, on the whole did well on being returned to duty. Those with generalized coarse tremor and those with hysterical walk, however, proved as a rule very unreliable ; and it became a routine to evacuate all such cases to the base. They seemed to be excessively unstable, emotionally, as compared with patients who suffered from hysterical mutism. The class most free from relapses was the simple exhaustion group. A week or ten days in hospital was invariably sufficient for complete recovery in such cases.

General Results of Experiences in France.

As a general summary of the experience amongst the nervous disorders of war in France, the following points are brought out :—

(1) In the forward areas, the majority of patients when placed under suitable conditions rapidly improved.

(2) The danger of confirming a patient's subjective symptoms if he were placed in a " sick atmosphere " was very great. Such patients were apt to be sent to England with their disorder firmly established.

(3) Except when hospital accommodation at the base was overcrowded, only 10 per cent. of cases admitted as N.Y.D.N. in the forward area needed evacuation to England.

(4) The best results from both the medical and the military point of view were obtained when the nervous disorders were treated in a special hospital at the earliest possible moment, and for this purpose each army N.Y.D.N. centre should be within convenient distance of the front line. The organization should ensure that efficient segregation of patients into the necessary wards was possible.

(5) Cases evacuated to the base from the army N.Y.D.N. centres should be received into hospitals detailed for this special work.

(6) Special medical officers for the various army centres and neurological centres at the base should be appointed, and the whole scheme for dealing with the subject of the psycho-neuroses should be co-ordinated by a consulting neurologist, who should lay down the lines of treatment and define the scope of the work to be attempted in the forward areas and at the base.

(7) A more intimate association between workers on the field and in the United Kingdom is essential for dealing successfully with the subject. The lack of co-ordination between the two was apt to produce deplorable results.

NERVOUS DISORDERS AS OBSERVED IN THE UNITED KINGDOM.

Early in the war it became evident that special arrangements would have to be made for dealing with the large numbers of neurasthenic cases which began to arrive from overseas.

Up to the end of November 1914 the only special accommodation for this class of case was in three civil institutions in London, namely, the National Hospital for the Paralysed and Epileptic, Queen Square, the Hospital for Epilepsy and Paralysis, Maida Vale, and the West End Hospital for Diseases of the Nervous System, Welbeck Street.

On 7th December, 1914, the Red Cross Military Hospital, Maghull, was ready to receive patients, but the first case was not admitted till the 21st of that month. This hospital was formerly the Moss Side State Institution and was the first mental hospital taken over from the Board of Control. In the first instance 300 beds were provided, and this number was subsequently increased to 500 by the erection of huts. A section of 35 beds for officers was added later at Quarry Brook House close by.

In January 1915 a special hospital for officers suffering from functional neurosis, traumatic neurasthenia and the milder psychoses was opened at 10, Palace Green, Kensington. This hospital was the first of a group of similar hospitals established at the instance of Viscount Knutsford. Neurological sections had also been established at the Royal Victoria Hospital, Netley, and the 4th London General Hospital, Denmark Hill.

In March 1915 the following procedure was adopted for the distribution of neurasthenic cases :—

The neurological sections at the Royal Victoria Hospital, Netley, and the 4th London General Hospital were constituted

" clearing " hospitals for such cases, and all neurasthenic patients arriving from overseas were sent to one or other of these clearing hospitals on disembarkation.

At the clearing hospitals cases were selected for transfer to one of the following neurological hospitals :—

(*a*) Red Cross Military Hospital, Maghull.
(*b*) Springfield War Hospital (a detached block of the County of Middlesex Asylum, Wandsworth, which had recently been taken over from the Board of Control and was about to open).
(*c*) National Hospital for the Paralysed and Epileptic, Queen Square.
(*d*) Hospital for Epilepsy and Paralysis, Maida Vale.
(*e*) West End Hospital for Diseases of the Nervous System, Welbeck Street.

In May 1915 it was found that the accommodation for neurasthenic cases which had been provided in the hospitals mentioned above was likely to prove inadequate, and commands were consequently instructed to establish neurological sections in such territorial force general hospitals as were considered suitable for the purpose. Lieut.-Colonel W. Aldren Turner was appointed by the War Office to advise commands and hospitals on the general arrangements for neurological cases and on the methods which it was considered advisable to adopt for studying and recording them.

In April 1916 revised instructions for dealing with neurasthenic cases were issued. Under these instructions soldiers suffering from traumatic neurasthenia, functional paralysis, and the milder psychoses arising from shock, exposure, and other factors incidental to service were sent in the first instance to one of the two clearing hospitals for a preliminary course of treatment.

From the clearing hospitals cases were distributed as follows :—

(1) Those requiring special but not prolonged treatment to :—

(*a*) National Hospital for the Paralysed and Epileptic, Queen Square.
(*b*) Hospital for Epilepsy and Paralysis, Maida Vale.
(*c*) West End Hospital for Diseases of the Nervous System, Welbeck Street.
(*d*) Neurological sections of territorial force general hospitals.

(2) Severe or protracted cases requiring more prolonged treatment to :—

(*a*) Red Cross Military Hospital, Maghull.
(*b*) Springfield War Hospital, Wandsworth.

Cases which it had not been possible to send through a clearing hospital, and all other cases arising in central and military hospitals where there was no neurological section, were at first given a short period of treatment, and those not responding to treatment within two or three weeks were transferred to the neurological section of the nearest territorial force general hospital, the severe or protracted cases being sent to Maghull, Springfield, or the Maudsley Neurological Section of the 4th London General Hospital, Denmark Hill. Cases occurring in Ireland were to be transferred to King George V Hospital, Dublin, and in Scotland to the Royal Victoria Hospital, Edinburgh.

Men discharged from the Springfield War Hospital or the Red Cross Military Hospital, Maghull, as fit for light duty were not to be sent overseas for a period of twelve months from the date of discharge from hospital, and then only provided a travelling medical board found them fit for service at the front.

Additional hospitals for neurological cases were subsequently opened from time to time, and in June 1918 the following special hospitals had been established :—

For officers :—

Maudsley Neurological Clearing Hospital (formerly a section of the 4th London T.F. General Hospital), Denmark Hill.
Special Hospital for Officers, 10 and 11, Palace Green, Kensington.
Red Cross Military Hospital, Maghull, Quarry Brook Section.
Officers' Hospital, Nannau, Dolgelly.
Neurological Section, King's Lancashire Military Convalescent Hospital, Blackpool.
Craiglockart War Hospital, Edinburgh.

For other ranks :—

Maudsley Neurological Clearing Hospital (with the three London civil institutions in Queen Square, Maida Vale and Welbeck Street, mentioned above, as sections).

Springfield War Hospital, Wandsworth.
Red Cross Military Hospital, Maghull.
Abram Peel Hospital, Bradford, Yorks.
Ewell War Hospital, Epsom.
Monyhull Section, 1st Southern General Hospital, Birmingham.
Glen Lomond War Hospital, Fife.
Dunblane War Hospital, Perthshire.
Seale Hayne Neurological Hospital, Newton Abbot.
Gateshead War Hospital, Stannington, Newcastle-on-Tyne.
Neurological Section, 4th Southern General Hospital, Plymouth.
Brinnington Neurological Section, 2nd Western General Hospital, Stockport.
East Preston Military Hospital, near Worthing.

These hospitals provided special accommodation for a total of 1,200 officers and 4,500 other ranks. In addition, there were some 400 beds in sections of various central hospitals.

A new method of disposing of neurasthenic cases was also instituted at this time, and all who were no longer in need of hospital treatment were examined by a neurological board at the special neurological hospital, to decide whether or not they were fit for any form of military service.

Those fit for further service were discharged from hospital to furlough under the heading " Employments," and the medical history sheet was endorsed in red ink " Neurasthenic—not to be sent overseas until re-boarded by a neurological board under A.C.I. 712 of 1918." On rejoining his unit the soldier was placed on some suitable employment in accordance with the recommendation of the neurological hospital, and the highest category in which he could be placed was " B.(i) Home Service only."

At the end of six months from the date of discharge from a neurological hospital the soldier was re-examined by a neurological medical board, unless in the meantime he had been discharged from the service or transferred to the reserve. At this re-examination the neurological board had to decide :—

(*a*) Whether the soldier was fit to be sent overseas, and, if so, in what category.
(*b*) Whether he should remain in his present category, and, if so, for what period.
(*c*) Whether he should be discharged from the service.

In the case of (*c*) the man was readmitted to hospital and steps taken for his discharge from the service.

The following additional hospitals were opened later on in 1918:—

Oulton Hall Hospital for Officers—71 beds.
Ashhurst War Hospital, Littlemore, Oxford—580 beds.

Towards the end of 1918 special centres of from thirty to forty beds were established at a central hospital in each command for dealing with epileptics other than those with mental symptoms.

In selecting hospitals for the treatment of neurasthenic cases, special consideration was given to the amount of ground available on which the patients could be employed on agricultural work for which a small hourly payment was allotted. This employment of neurasthenic patients on agricultural work and payment for the work done was first instituted at the Red Cross Military Hospital, Maghull, where it met with marked success both from the curative and the financial point of view. The system was extended as far as facilities allowed to other neurological hospitals, notably to Seale Hayne Military Hospital which was established in the Seale Hayne Agricultural College, where exceptional facilities were available for employing patients on farm work.

Courses of instruction were organized at the Red Cross Military Hospital, Maghull, and between December 1917 and March 1919, 56 R.A.M.C. officers, six officers of the Canadian Army Medical Corps, and five of the United States Medical Corps passed through a three months' course there. Such a short course was insufficient to teach the subject of mental diseases and their treatment, but, as far as the time would allow, the officers, by lectures, demonstrations and clinical experience, were trained to undertake the care of such cases, and it was possible to provide staffs for the various hospitals which were being opened throughout Great Britain. At the time of the armistice in November 1918, there had been provided about 1,000 beds for officers and 5,000 beds for other ranks.

The Maudsley Neurological Clearing Hospital and its dependencies, being one of two clearing hospitals for these patients, admitted a total of 12,438 cases, whether battle casualties or "sick," as follows: October to December 1915, 777 patients; in 1916, 3,950 patients; in 1917, 2,383 patients; in 1918, 3,097 patients; and in 1919, 2,231 patients.

At the time of the armistice, therefore, much had been done to make it possible for the cases of mental disturbance to receive treatment at an early period, and their recovery was thereby rendered more easy and more rapid. But there is no doubt that throughout the war the evacuation of many, if not of most, cases from France could have been avoided to a considerable extent if trained men, capable of undertaking the treatment of this type of case, had been available so that a special service near the front line could have been organized. The value of prompt and efficient treatment in the earliest phases of the illness is demonstrated by the account in the preceding pages of the work done in the N.Y.D.N. centre of No. 62 Casualty Clearing Station.

Ætiology and Symptoms of Cases in the United Kingdom.

Although there was a large incidence of nervous and mental disturbances there has been no important addition to the symptomatology of these conditions. It has long been known that in what are termed the neuroses and the psycho-neuroses the function of every organ of the body can be disturbed, and all such disturbances have been fully enumerated and described by various authors. Much that has been written on the subject during the last few years has consisted in a further enumeration of symptoms and a harvest of definitions and of hypotheses to explain the conditions referred to.

There has been in the past a tendency to judge the mental condition of a patient according to his behaviour in relation to social conventions; that is to say, conduct not conforming to the ordinary rules of society has been considered abnormal and indicative of insanity. It is true that such abnormal conduct may be the result of morbid stimuli and therefore rightly diagnosed as true mental disease, but on the other hand it is now recognized that it may be an excessive reaction along natural lines to stimuli which did not have their origin in morbid conditions. Thus in the cases under consideration fear is a normal instinctive reaction to a position of danger; horror is a normal feeling in response to some ghastly incident at the front, and so forth. Whether a mental illness will follow some intense stimulus experienced depends on the interaction of a large number of factors, psychic and physical.

In the first place, the mental illness seen in the patient after his return to England has to be carefully distinguished from the condition of exhaustion and confusion which followed immediately after the shock was received. In many instances, the patient recovered from the earlier condition after a few days' rest; and by many patients in whom a further illness developed it was recognized as a preliminary stage. Evidence of this is found in the statement of one man that "it was when I was getting stronger that this came on." He had been "blown up" and was recovering when "this came on." His further illness was not directly connected with the explosion of the shell which overcame him, but depended on the recurrence of the memory of a distressing incident which had occurred some weeks before he was "blown up." This incident had led him to feel that he had on one occasion behaved as a coward, and the memory of it had produced such a feeling of misery that he had exposed himself deliberately on many occasions in the hope that he might be shot. His power of control was further weakened by the shock of the explosion of a shell which rendered him unconscious, but he recovered from the effects of this in a few days. It was when he was getting stronger, that is, when he was recovering from the exhaustion and confusion which immediately followed the accident, that he became obsessed by the memory. His mind was occupied with it during the day and he had distressing dreams of it at night, until at last he was dominated by it to such an extent that suicide seemed the only way of escape. In this instance, the reaction to the act which led him to call himself a coward, namely remorse, was a perfectly normal one and it was reproduced whenever the memory of the act was revived.

This illustrates very clearly one of the processes of ordinary mental activity. It is now recognized that with every stimulus that crosses the threshold of consciousness there is experienced not only the recognition of what has happened but also an emotional tone specific to it, and when the memory of the experience is recalled a similar emotional tone is re-awakened. Repetition of this process, day after day, will lead to the formation of a habit of mind so that only a trifling stimulus is at last required to bring the memory with its emotion into consciousness, especially if the power of control has been weakened by fatigue, illness, accident or shock of any kind. Questions such as, "Why do I get these terrors?" "Why am I always seeing those things that happened in France?" "Why am I so irritable?" "Why do I get so upset?" are frequently heard from patients. In almost every instance the memory of some disturbing past experience will be found acting as the cause.

The patient then feels that his ordinary mental activity is interfered with. He cannot perceive, think of, feel with regard to, and judge of everyday events occurring in his environment as he has been accustomed to do, and therefore he cannot act so as to adapt himself to that environment. One of the most common complaints in these cases is that the patient cannot keep his mind fixed on any given subject, that he loses himself, so that he cannot remember what he has done or what has happened to him. This disability may vary in degree from a slight disturbance of attention up to a complete dissociation with somnambulism or fugue. Such an interference with normal mental activity will be discovered, on investigation, to exist during the early stages of all types of functional mental illness, and the constant repetition of this process cannot but lead to the development of a state of anxiety as to what it may mean and to what it may lead.

Another series of phenomena, which must be considered as normal but which may be a source of great difficulty, includes the physical or somatic manifestations accompanying the emotional states. These manifestations are necessarily repeated with each revival of the cause in consciousness, and they lead patients to enquire: "Why do I get these tremors?" "Why do I sweat so?" "What is wrong with my heart?" "Why am I so giddy?" "Why do I get the feeling that my stomach is rolling over?" Sometimes they recognize that peculiar somatic reactions occur with special mental states. One man remarked, "Whenever I get excited my nose gets blocked!" and another that "I know that if I get excited these swellings will come up!" In this case the swellings consisted of local vaso-motor reactions or erythematous patches situated under the left eye, on the chin, on the left shoulder, and on the chest. Misunderstood by the patients, these reactions confirm the fear that some serious organic lesion exists, and they may play an important part in maintaining the disability.

During recent years, however, changes which occur in other internal organs have come to be regarded as forming part of the general disturbance of the organism in illnesses of this nature. The functions of the endocrine glands are now known to be influenced in intense emotional states, and their secretions may be altered in quantity and possibly in quality. Because of this, not only may the sensitivity and reactivity of the nervous system be appreciably modified, but the metabolism and nutrition of the body may also be seriously interfered with, and this may lead to a feeling of ill-being in the patient. The action of all these influences together with an almost complete lack of knowledge of the processes concerned may lead to a breakdown in which the patient feels that his ordinary mental activity is disturbed, that he cannot adapt himself to his surroundings, and that his body is affected as well as his mind. When in such a condition, not only does the patient fall into a state of anxiety, but he feels the necessity of obtaining some explanation of his illness. He is, therefore, open to any suggestion that may come to him from what he sees, from what he hears, from what he feels in himself, and very frequently from suggestions made to him by doctor or nurse. A remark about his accident, placing a limb on a splint, the daily application of electricity and massage, pain on movement, or a fall on the first occasion on which he gets out of bed after weeks on his back, or a feeling of weakness and exhaustion, may be sufficient to lead to a pondering on his condition and an observation of trifling difficulties which may cause a complete disability of one or more limbs to develop. For instance, great difficulty in moving a leg was observed in the case of one patient who was hit in the buttock by a bit of shell. A hæmatoma appeared, and in order to obtain relief the man placed the limb in a peculiar angular position. A certain amount of pain and discomfort naturally followed the using of the limb in such a position, but it was enough to lead the patient to think that there was some permanent disability, even after the hæmatoma had completely disappeared.

Another example may be given of a man who was seen in hospital within twenty-four hours of his being "blown-up," and who complained that when the explosion occurred he heard something go "crack inside his head." A conversation was carried on with him for a quarter of an hour, and then it was pointed out to him that he still possessed and was capable of using all his faculties, that he could hear and give attention to what was said, that he could consider it and form a judgment, that his memory was good, and that he felt correctly with regard to subjects brought to his notice. His reply was, "Yes, sir, but what was that which went crack inside my head?" Such an idea would in itself be quite sufficient to lead him to watch for and to note any difficulty or confusion in thought, any pain in the head and any peculiar sensations, and to see in them a confirmation of the fear that something had happened inside his head. Later he might adopt some bizarre idea to explain his difficulties to himself.

But there are still other factors to be considered in the production of mental illnesses and the type of disturbance that may appear. Foremost amongst these must be recognized the influences experienced during childhood. In 1915, when the patients admitted to hospital were drawn from the regular army, that is, the original expeditionary force, it was remarkable to note the number of patients who had apparently had an unfortunate childhood. Many of them seemed to have enlisted in the army to escape from a world which had been hard on them from their early years. Some had grown up with a lack of confidence in themselves, and they regarded the army as a haven of rest where, at any rate, they would be taken care of, would have little responsibility and would not be called on to exercise much initiative. In other instances they developed a feeling that they were "up against" everything and everything was "up against them." They were morose, and discipline seemed to give rise to a sense of grievance, as though it had been especially directed against them.

Such types of personality were not likely to be able to withstand the strain of the first months of the war, and many of them broke down and fell into a condition of anxiety and misery. One patient, whose mother had been an episodic drinker, had had a previous illness when 16 years of age. From his childhood he had always experienced a difficulty in facing the world, and for him the strain of the war at once proved to be too much and he returned from France in a helpless condition after a very short time. Many similar cases could be mentioned which exhibited a hyper-sensitivity and hyper-reactivity of the nervous system, so that some trying experience, such as being "blown up," or some horrible sight or act could easily render them incapable of further service, at least for a time.

But it must not be inferred that all those who suffered from a nervous breakdown belonged to these categories. The experiences in those early days, and also subsequently, were so terrible as to be capable of overwhelming even the strongest. As the war went on it was not infrequent to find men who had done one, two, or three years' hard service, but for whom the strain had at last proved too great. Often in these cases there had occurred some other incident, such as an illness or some serious occurrence at home, which had acted as disturbing agent, and then the strain had been felt more acutely. The fact that they had broken down was the cause of sincere distress to them; they were filled with shame and with disgust at their condition.

It should be mentioned that amongst the cases which returned to England it was rare to meet a definite attempt at malingering. The illness was a real disability, and as a rule the response to treatment was prompt and satisfactory. But it was probably true that the further the invalid soldier went from the front line the more difficult it was to get him back to it. There is little doubt that the fact of his having crossed the narrow strip of sea afforded him a sense of relief, a sense of safety, a feeling of escape from the terrible conditions of existence on the other side, and quite naturally there arose a desire not to return. This may have had an influence on the will to recover on the part of the patient, but the chief factor was that he felt he had broken down once and he feared another disaster if he were again subjected to a similar strain.

It must also be recognized that the treatment the soldier received in many of the general hospitals in England was not such as would assist him to recover quickly. He was often neglected and was shown quite plainly that he was not wanted. He was transferred from hospital to hospital; in many instances a man passed through more than a dozen hospitals, and practically in all of them was left to his own resources to get better. The accusation of malingering, therefore, which was so readily levelled at the soldier was not justified, but, on the other hand, he might reasonably have developed a grievance that treatment was so long delayed and was perhaps so unsuitable for the type of illness.

With regard to the further developments of the illness it was found that, just as the symptoms of organic disease of the nervous system could be reproduced in functional disturbances, so the syndromes of all types of mental disease were met with among the soldiers who broke down during the war. Motor, sensory, and autonomic symptoms occurred in every variety and in every degree, and also psychic syndromes appeared to illustrate all types of mental illness, slight and severe, from hysterical manifestations to acute psychoses. It was possible in many cases to elucidate the causes which had led to this or that disability and to the particular form that it assumed.

Some of the examples already given illustrate the part played by suggestion in producing the results observed. These included disturbances affecting all the organs of the body, motor and sensory, those of the special senses and those connected with the vascular, respiratory, digestive, genito-urinary and secretive systems. A detailed reference to the symptomatology is not necessary; they are similar to those fully described in text-books. No fresh details of importance were observed amongst those who suffered as a result of war experiences.

Diagnosis of Cases in the United Kingdom.

Amongst the group of what are generally considered the more severe psychic disturbances there occurred all types and degrees of illness. In some the states of anxiety already referred to persisted and gradually became more fixed and more dominant as time went on. Many were on the borderline of insanity and in ordinary circumstances would undoubtedly have been certified and segregated. But living as they were in a hospital, having few responsibilities and receiving allowances which kept them and their families from want, they were able to adapt themselves sufficiently to their surroundings to escape certification and in time they reacted to treatment and recovered.

Others, by their appearance and behaviour, suggested that they belonged to the class of defectives, and considerable difficulty was experienced in making a diagnosis until their personal history up to the time of the war was investigated. Then it was often found that they had done satisfactorily at school and had worked well afterwards, and the question was at last solved by their improving under treatment and showing that they were not of low intelligence.

Difficulty of diagnosis was also frequently encountered in cases which, at the time of observation, showed symptoms characteristic of the psychotic conditions. Especially interesting were those which, excepting that the Wassermann reaction was negative, strongly suggested an early stage of general paralysis ; psychic, motor and sensory signs of the disease were present for a time, but gradually disappeared. In other instances conditions illustrating dementia præcox and paranoia existed ; maniac-depressive states and epileptic attacks also were frequent. All types of mental illness, therefore, were represented, and to the surprise of the observers, many cases belonging to all these categories, in whom the prognosis at first appeared unfavourable, slowly improved and were discharged as being capable of earning their living.

The case of a soldier who exhibited a remarkable combination of psychic, neurological, and autonomic symptoms may perhaps be quoted :—

Amongst the psychic symptoms were acute depression, confusion, stupor and epileptic attacks. The neurological signs included difficulty of speech, sometimes tremors of the arms and legs, at other times slow stiff movements ;

the reflexes were altered and varied at different examinations. The Babinski sign was now present and now absent; there was much difficulty in walking, frequently he crossed his feet and tumbled. Amongst the autonomic signs were found a diffuse œdema of the skin of the head and neck; dilatation of the vessels of the limbs, with cold and blue extremities such as are often seen in dementia præcox; sluggish, unequal pupils, furred tongue, excessive salivation, incontinence of urine, and constipation. Some of the autonomic symptoms were almost constant; the neurological signs varied a little and the psychic disturbances to a great degree, from stupor through a slight hebetude to comparative clarity of mind. The fits of depression were temporary, but frequently repeated.

Later he had a very severe attack. The depression was more intense, the stupor deeper, the fits more numerous; he lay in bed gazing at the ceiling; he did not respond when spoken to; he required to be fed, and there was marked incontinence of urine and constipation. His tongue was thickly coated, the salivation persisted; in fact, all the symptoms were exaggerated. At this time he described some obsessions of a horrible character which had taken possession of his mind.

But from this time he began to improve. Two months later it was noted that he had been a little depressed for a day or two, but that there had been no attack of any sort for six weeks. He said, " I know that if I gave way to the thoughts I should go back again." Some stiffness of the arms and legs remained, but there had been no fits and no stuporose attacks. The reflexes had become normal; the pupillary reactions were normal. The tongue was clean, the appetite good, the salivation had ceased; and the incontinence of urine and the constipation had both disappeared. This improvement continued. He had some slight depression occasionally, but otherwise he progressed satisfactorily.

This case is a good illustration of the fact that associated with a psychic illness there may occur a disturbance of the function of any or all of the organs of the body, and also that psychic, neurological and autonomic symptoms strongly suggested the existence of a grave organic lesion. The disturbance, however, was eventually proved to be purely functional, and the normal functions, mental and physical, were restored when the psychic cause was removed.

Prognosis of Cases in the United Kingdom.

In February 1921, statistical evidence showed that, as already noted, approximately 65,000 men were drawing pensions for disability due to neurasthenia and allied conditions which had arisen in connection with the war, and that in January 1922 this figure had decreased to 50,000.

In order to obtain more exact figures enquiries were instituted by the Ministry of Pensions for two different periods in 1921, the first comprising the month of February, the second the first twenty-eight days of November.

During the first period there were in hospital or attending boards or clinics 14,771 cases of neurasthenia and similar complaints, excluding all cases of definite mental deficiency or disorder. These were grouped into four classes. In the

November period the numbers were 16,393. The following table shows the grouping of these cases in the two periods, with the proportion in each group.

TABLE VII.

Groups.	1st to 28th February, 1921.		1st to 28th November, 1921.	
	Number.	Per cent.	Number.	Per cent.
Class I. Cases definitely attributable to shell shock, *i.e.*, explosions of all kinds (commotion)	5,189	35·1	5,058	30·9
Class II. Cases due to general war stress (emotion), and developing before discharge from the service	8,215	55·6	9,974	60·8
Class III. Cases due to general war stress (emotion), but developing after discharge from the service..	1,046	7·1	1,053	6·4
Class IV. Cases due to social and family conditions and financial distress developing subsequent to war service	321	2·2	308	1·9
	14,771		16,393	

It will be seen that Class II had increased in the second period by 1,759, and Class III by 7, while Class I had diminished by 131 and Class IV by 13.

Those cases which were in hospital were examined in order to elucidate more fully the ætiology of the disease.

The part played by "other disabilities," such as other wounds and various medical disorders, was considered. It was found that the following percentages of the cases also showed other disabilities.

TABLE VIII.

Group.	Percentage showing other Disabilities.	
	February.	November.
Class I	50·7 per cent.	44·9 per cent.
Class II	54·3 ,,	54·6 ,,
Class III	58·6 ,,	65·6 ,,
Class IV	43·3 ,,	55·9 ,,

The number of patients who from their family history, from former illness or disease could be regarded as "potential neurasthenics" at the time they joined the service was shown as follows :—

	February.	November.
Class I	20·8 per cent.	13·5 per cent.
Class II	32·8 ,,	26·3 ,,
Class III	21·8 ,,	23·6 ,,
Class IV	49·2 ,,	40·4 ,,

Enquiry was made as to various causal factors, such as service in tropical countries, influence of malaria and other diseases, exposure, overwork, fear or anxiety, chronic pain, and insomnia. Of these, fear or anxiety appeared to be the only important item. It was attributed as a causal factor in Class II in February to 64·8 per cent., in November to 44·8 per cent. of the cases ; in Class III in February to 58·5 per cent. and in November to 33·9 per cent. of the cases. In Class IV, allied conditions, financial anxiety, family troubles and unemployment were allowed as causal factors in February to 100 per cent., in November to 85·7 per cent. of the cases.

In Classes III and IV the period between discharge from the service and the onset of the disease was found to be distributed as shown in Table IX.

TABLE IX.

Date.	Period between Onset of Disease and Discharge from Service. Number of Cases.			
	Under 6 months.	6 to 12 months.	1 to 2 years.	Over 2 years.
February	234	93	22	6
November.. ..	170	87	70	54

These figures give rise to certain reflections. In the first place, though the total number of such pensioners is small in relation to the number of men who during the war were at one time or another under arms, yet it is remarkable that after three years of peace so great a number should remain disabled. It is to be feared that a large proportion of them will never recover their full mental capacity.

In the second place, it is clear from Classes III and IV that the effect of war may be felt for a long time after actual fighting has ceased. It had been expected that when once the war had ended no fresh cases of this kind would present themselves. Yet it has been within the experience of many medical men to see individuals with whom they were privately acquainted break down, sometimes many months after the armistice had been signed, and even after demobilization. It has been reported by medical officers that in Class IV may be found men of excellent character, some of them decorated for gallantry, who returned to their original employment at the end of the war without suffering any anxiety, and pursued it with success for a considerable period, but yet without any apparent cause have later become pronounced neurasthenics. This alone would be sufficient evidence, if any were required, that this disease is a real and very serious consequence of war, and further that it is one of the most prolonged and most difficult to cure.

In organic disease it is not difficult to estimate the average number of days during which hospital treatment is required, and the average number during which the patient is absent from the ranks. In the present case such calculations are of little value. In France, a man restored to duty from a neurological centre in the forward area usually rejoined his unit within the month ; if evacuated to the base the time was much prolonged, and if sent to England the duration of hospital treatment was longer still, and the tendency to regard such men as unfit for further field service increased as experience grew. The lack of accommodation and of special hospitals for such cases in the early years of the war are additional factors which would invalidate the formation of any general judgments.

It might be thought that a more stable condition had now been reached. From returns of the Ministry of Pensions the following statistics have been compiled.

During the period 26th June to 30th September, 1921, 1,947 patients were discharged from neurological hospitals as follows :—

Recovered	399 = 20·5	per cent.
Relieved	1,003 = 51·5	,,
Unimproved	224 = 11·5	,,
Misconduct..	211 = 10·8	,,
Unsuitable for treatment..	110 = 5·6	,,

But in this return the diagnosis of the condition on discharge varied considerably in different areas. Thus, those who were discharged as " recovered " formed only 4·4 per cent. of the total discharges in the London district, whereas they formed 32·6 per cent. of the total in the remainder of the hospitals in the United Kingdom. But the classes labelled "recovered" and "relieved" taken together came to much the same total in the two areas. Such a difference evidently depends more upon the personal opinion of the medical officer than upon either the condition of the patient on admission or the character of the treatment employed.

During the same period, 3,408 patients were discharged from neurological clinics, grouped as follows :—

Recovered	785 = 23·3	per cent.
Relieved	1,697 = 49·5	,,
Unimproved	284 = 8·3	,,
Misconduct..	238 = 7·0	,,
Unsuitable for treatment..	404 = 11·9	,,

The number of patients who during treatment in the clinics were in employment was 1,159 or 34 per cent. The number who were discharged to employment from the clinics was 527 or 15·5 per cent., and from the hospitals 413 or 21·2 per cent.; a total of 940, or 17·5 per cent.

During the period 1st–25th December, 1921, 1,662 patients were discharged from neurological hospitals as follows :—

Recovered	317 = 19·1	per cent.
Relieved	738 = 44·4	,,
Unimproved	281 = 16·9	,,
Misconduct..	202 = 12·1	,,
Unsuitable for treatment..	124 = 7·5	,,

During the same period 4,099 were discharged from neurological clinics, grouped as follows :—

Recovered	948 = 23·1	per cent.
Relieved	1,721 = 42.0	,,
Unimproved	578 = 14·1	,,
Misconduct..	308 = 7·5	,,
Unsuitable for treatment..	544 = 13·3	,,

The number discharged to employment from the clinics was 525, and from the hospitals 370.

But even this does not go very far, for this is a disease which has a great tendency to relapse. Even cases treated in the early stages in France seem to have included 20·5 per cent. of relapsed cases and the tendency is still more marked as the illness becomes more confirmed and habitual. In the Ministry of Pensions returns the discharged cases are indeed classed as "relieved" or "recovered," and it might be thought that the former might be expected to relapse and the latter to be permanent cures. But on looking into the return it becomes evident that this division is not made by any constant standard; it is influenced by the temperament of the doctor rather than by the symptoms of the patient, and it gives no criterion whether such cases are likely or not to require hospital treatment again.

The main fact that in February 1921 the total of men drawing pensions for neurasthenia and allied disabilities was 65,000, a number not greatly below the total of casualties estimated as having been admitted for this disability to medical units during the war, does suggest that the disability when once established is most protracted. There is no information as to whether any large proportion of those men who broke down temporarily during the war but were soon returned to duty did, when the pressure of active warfare finally died down, become conscious of the past strain and develop neurasthenic disabilities.

Treatment in the United Kingdom.

The treatment of this class of cases varied according to the point of view from which they were approached by the medical officer. Some seem to have regarded the terms "neurasthenia" and "shell shock" as being practically synonymous with malingering, and to have adopted methods appropriate to the latter condition. As would be expected, such treatment often led to the development of a feeling of revenge in the patient rather than to recovery.

On the other hand, some medical officers, rightly sympathising with their patients and anxious to give them the relief of confession, were prone to credit any story that the soldier might relate.

The first essentials in dealing with cases of this type are that the treatment should be undertaken at the earliest possible moment, and by a medical officer who has received adequate training in this difficult branch of medicine. The benefits to be derived from early and appropriate treatment were demonstrated in the hospitals which were established behind the front line. In the United Kingdom the ill-effects of delay were evident and often serious. But in 1918, when the special hospitals were available and were staffed by trained officers, and arrangements were made to allow of the patients being distributed to these hospitals more directly after their return from France, results similar to those in the army centres were also obvious amongst patients treated in home hospitals.

The hospitals differed much in the type of patient admitted and in the methods of treatment employed. In some as many as 80 per cent. of the cases were of the type known as the "conversion hysterias," and only about 20 per cent. belonged to the anxiety group; in others the anxiety group preponderated.

In the former category were included the motor, sensory, special sense and vocal disturbances. In the treatment of these all varieties of suggestion were employed, different procedures being required for special conditions and special types of illness.

With the anxiety group were associated many examples of the condition of disordered action of the heart, which occurred so frequently as really to form part of an anxiety neurosis. It was difficult to convince these patients that there was no definite organic disease of the heart, and that the palpitation, giddiness and weakness, which were so real to them, were the result of an emotional reaction. But good results were obtained in them as in the other cases in this anxiety group by the application of modern methods of psycho-therapy in some form or other. A simple explanation of the mechanisms of ordinary mental activity enabled the patient to understand how some incident in his experience could act as a disturbing influence. He could also see the importance of an examination being made in order that this disturbing incident might be recognized and discussed, and he was thus enabled to face his difficulties and to re-educate himself in order to adapt himself to them instead of merely enduring them or endeavouring to forget them.

Under these various methods of treatment the patients often improved rapidly and became fit to undertake some manual work in hospital, or in a specially arranged camp such as was established at Blackpool. They were thus assisted to recover sufficiently to return to civil life or to proceed to a command depôt for a course of graduated training. In the last year of the war, however, it was decided that it was not advisable to send soldiers who had suffered from a nervous breakdown for further duty in the army, and the great majority were discharged to civil life.

There remained, however, a considerable number of cases which were in such a condition of acute mental illness that nothing could be done for them in general or special hospitals. Many of these men had had previous attacks during civil life which had required their being segregated in an asylum or had for a time incapacitated them from following their employment. In others the early signs of general paralysis, of dementia præcox, or paranoia, or some other severe disturbance had, if reliance can be placed on their mental state, existed at the time of their enlistment. Others, again, possessed such an unstable nervous system that the strain of war conditions aggravated their condition so much that an acute psychosis soon developed.

Prevention.

There remains the question whether in future any steps could be taken to prevent the disease by excluding from enlistment men who were likely to become subject to it. It was found in the course of the enquiries made by the Ministry of Pensions, referred to above, that the average duration of service in the field among these patients had not exceeded eighteen months, and it would be therefore advisable, if it were possible, to save the country the heavy expense to which it is liable by engaging these men. But, on the other hand, it may be questioned whether a large proportion of these cases is not due to want of provision for early treatment. The results obtained in France when such provision had been made seem to show that only a very small minority fail to respond to treatment if applied at once.

Owing to a debate in the House of Lords on the 28th April, 1920, a committee was appointed by the War Office to consider the different types of hysteria and traumatic neurosis commonly called shell shock ; to collate the expert knowledge derived from the experience of the war, with a view to recording for future use the ascertained facts as to its origin, nature and remedial treatment ; and to advise whether, by military training or education, some scientific method of guarding against its occurrence could be devised. Lord Southborough who initiated the debate was appointed Chairman. The Committee met for the first time on the 7th September, 1920, examined 59 witnesses and held 41 sittings. Its report was eventually published in August 1922, some time after this chapter on Nervous Disorders was in print. It has not been possible therefore to recast the chapter in order to embody the facts brought out in that important document, and for full details of the evidence and recommendations in it, the report itself should be consulted.

As regards the main points, however, relating to the origin, nature and remedial treatment of war neuroses, the essential facts in the Committee's report correspond with the points recorded in this chapter. On the other hand, the details for measures of prevention are much more fully recorded and discussed and some further reference to them is desirable. Great importance is attached by the Committee to the effect of discipline, moral, *esprit de corps*, training, leadership, selection of suitable regimental medical officers, and rest and comfort in the prevention of nervous disorders on active service.

After a preliminary note to the effect that the term " shell shock " should be eliminated from the official nomenclature ; that abbreviations such as N.Y.D. nervous or mental, or N.Y.D.N., etc., should be avoided ; and that the disorders hitherto included under the heading " shell shock " should be designated by the recognized medical terms for such conditions, they recommend, with regard to prevention, the following measures :—

" (A) Training.—1. Every possible means should be taken to promote *moral, esprit de corps* and a high standard of discipline.

2. Training should be sufficiently prolonged to ensure that the soldier is not only physically fit and efficient, but also that he has had time to acquire such a standard of moral as will enable him to put the welfare of his unit before his own personal safety.

3. Close observation should be made by officers, both regimental and medical, and by non-commissioned officers of the unit on individuals during the whole of their training, so that abnormalities from which mental or nervous instability may be inferred may not be overlooked. For this purpose there should be the frankest co-operation between regimental and medical officers.

4. The study of character, so far as it is applicable to military life, is recommended for all officers with a view to teaching Man-Mastership.

5. Special instruction should be given to Royal Army Medical Corps officers in the psycho-neurosis and psychoses as they occur in war, and selected officers should be encouraged to specialize in the study of these disorders.

(B) On Active Service.—1. The practice of withdrawal of officers and men showing incipient signs of nervous breakdown or over-fatigue for rest either in the battalion or divisional area should be officially recognized and systematized.

2. So far as the military situation permits tours of duty in the front line in stationary warfare should be short, especially in bad sectors. Adequate rest and organized recreation should be provided for units when out of the line.

3. Monotony should be avoided by changing units, as circumstances permit, between fronts and sectors.

Leave home should be encouraged.

4. The promotion of all measures making for good sanitation and the physical comfort of the men, both in the line and also in rest billets and base depôts, should receive constant attention.

5. Rest of mind and body is essential in all cases showing signs of incipient nervous breakdown, and when possible it should be given under conditions of security and comfort and freedom from all military duties.

6. The fullest use should be made of convalescent depôts for re-training and hardening men discharged from hospital. These units should invariably be pervaded by an atmosphere of complete cure."

In addition the Committee recommended that every effort should be made at the time of enlistment to ascertain the nervous and mental conditions of candidates both from their previous histories and from their present condition, and that all medical officers of the Regular, Special Reserve and Territorial Force should undergo a prescribed course of instruction in the methods of examination of recruits and the physical and mental standards required. The instructions issued for the guidance of medical boards by the Ministry of National Service during the war were regarded as indicating the standard of examination which was most likely to succeed in eliminating those men who would be liable to suffer from mental or nervous breakdown in war. But the difficulties of recognizing "potential neurasthenics" at the time of general enlistment were recognized to be great; and observation of the recruit during his period of training was considered a more reliable method of detecting those who were likely to be unfit for front line service.

The conditions which, in the opinion of the Committee, should prevent soldiers who had suffered from war neuroses being returned to the fighting line were as follows :—

"(1) If the symptoms of neurosis are of such a character that the soldier cannot be treated overseas with a view to subsequent useful employment.

(2) If the breakdown is of such severity as to necessitate a long period of rest and treatment in the United Kingdom.

(3) If the disability is anxiety neurosis of a severe type.

(4) If the disability is a mental breakdown or psychosis requiring treatment in a mental hospital.

It is, however, considered that many of such cases could, after recovery, be usefully employed in some form of auxiliary military duty."

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CHAPTER II.

SKIN DISEASES.

DISEASES of the skin, if syphilis is excepted, are generally regarded as lesser maladies, that is to say, conditions which as a rule neither threaten life nor seriously impair health. For the individual this is true, but in the case of an army the collective results of such minor affections may become of high importance because, for military purposes, a man incapacitated for duty is a loss to the fighting force whatever the extent or cause of his personal disability.

The records of the war show that amongst the troops in France the incidence of skin disease was considerable. In one army, in the later stages of the war, it is stated that the more common diseases were scabies, infections of the skin and pyrexia of unknown origin, and that these conditions accounted for 90 per cent. of all the sickness. Such a statement is equivalent to an expression of the paramount importance

TABLE I.

Admissions to No. 26 *General Hospital.*

	1915.		1916.						Total.
	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	
Impetigo	122	172	151	161	220	170	147	116	1,259
Boils	24	59	50	51	42	36	65	48	375
Scabies	95	770	170	8	25	5	9	23	1,105
Dermatitis ..	7	10	10	11	11	8	8	7	72
Psoriasis	11	24	17	17	29	21	36	29	184
Seborrhœa ..	8	12	13	11	40	18	18	11	131
Eczema	7	22	18	11	37	22	33	31	181
Pediculosis ..	–	17	62	69	36	3	5	6	198
Erythema.. ..	3	7	5	–	4	1	–	1	21
Ecthyma	–	–	1	2	–	–	–	–	3
Pityriasis rosea ..	3	2	2	5	3	2	2	3	22
Folliculitis.. ..	1	11	13	9	8	2	5	1	50
Urticaria	2	4	3	3	2	11	8	1	34
Herpes zoster ..	2	2	2	–	3	3	1	–	13
Ichthyosis.. ..	–	–	1	–	–	–	–	1	2
Acne	6	22	19	12	8	6	10	7	90
Sycosis	4	2	4	1	3	2	5	7	28
Syphilis	8	13	4	3	6	4	17	16	71
Carbuncle.. ..	2	4	3	1	4	2	1	2	19
Lichen planus ..	–	–	1	1	–	–	1	–	3
Sudamina.. ..	–	–	–	–	–	–	–	2	2
Erythema nodosum	–	–	–	–	–	–	–	2	2
Lupus	–	–	2	–	–	3	2	2	9
Erysipelas.. ..	–	–	–	–	1	–	1	2	4

of scabies and pediculosis amongst the causes of medical disability, for it is to be remembered that pyrexia of unknown origin in its common form of trench fever was a sequel of pediculosis, while in most cases infections of the skin were due to pediculosis and scabies, one or both.

As early as 1915 skin disease was claiming considerable attention from the medical authorities. At that time it was noticed that many men in the drafts arriving in France were affected with scabies, and in consequence at Etaples, Boulogne and elsewhere special accommodation had to be provided for their treatment. Table I gives a statistical summary of the admissions of cases of skin disease in No. 26 General Hospital, Etaples, from November 1915 to June 1916.

TABLE II.

Admissions to No. 25 General Hospital.

	1916.					1917.			Total.
	Aug.*	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	
Impetigo	268	729	849	388	305	287	444	655	3,925
Boils	129	258	396	116	85	62	130	168	1,344
Scabies	92	223	201	54	135	143	183	161	1,192
Dermatitis	21	91	92	54	44	42	67	61	472
Psoriasis	24	40	34	41	38	32	52	46	307
Seborrhœa	7	24	25	19	46	34	70	69	294
Eczema	22	69	83	41	48	52	62	76	453
Pediculosis	8	14	8	14	13	8	14	4	83
Erythema	–	3	2	8	2	5	1	1	22
Ecthyma	–	–	2	3	3	–	1	3	12
Pityriasis rosea	–	2	9	2	4	1	–	3	21
Folliculitis	–	1	1	–	1	2	1	2	8
Urticaria	3	9	11	15	5	6	5	2	56
Papular urticaria	2	–	–	1	–	2	–	–	5
Herpes zoster	11	20	19	6	2	3	8	8	77
Ichthyosis	–	–	–	4	1	3	5	3	16
Acne	4	10	11	6	7	5	9	7	59
Sycosis	3	11	5	3	4	10	5	9	50
Syphilis	5	9	8	3	6	11	6	7	55
Carbuncle	22	26	43	6	1	–	1	6	105
Lichen planus	1	1	–	1	–	–	–	–	3
Sudamina	–	–	–	2	–	–	1	–	3
Lupus vulgaris and scrofulodermia.	2	2	2	2	–	2	3	2	15
Erysipelas	–	–	2	–	–	–	–	–	2
Ringworm	4	1	1	1	3	5	5	5	25
Hyperidrosis	2	1	–	–	–	–	–	–	3
Hyperkeratosis	1	–	–	–	–	1	–	–	2
Rosacea	1	–	–	–	–	1	–	–	2
Alopecia	–	–	1	–	–	–	1	–	2
Lupus erythematosus.	–	–	–	1	–	–	1	–	2

* From 9th August.

Although examples of many different varieties of skin disease were met with in the various armies, the parasitic affections always formed the most numerous and most important group. As these parasitic disorders increased in number with the growth in size of the forces, it became evident in 1916 that it would be advantageous to establish a central hospital for dealing with skin diseases for the Boulogne and Etaples areas, and for this purpose No. 25 General Hospital at Hardelot was selected. Table II shows the admissions for skin disease into this hospital from August 1916 to March 1917.

While these and similar figures, however, accurately represent the state of the patients on admission, they fail to show the important relationship between scabies and pyodermia. To obtain information on this point an analysis was made of a series of 1,000 consecutive admissions diagnosed as scabies, boils or impetigo. In this series separate note was made of all cases of impetigo or boils following scabies, which would be recorded in the above tables simply as impetigo or boils, because on the patient's arrival at the base the primary scabies had been cured. The details of this analysis are given in the following table.

TABLE III.

Analysis of 1,000 *Consecutive Cases admitted as Scabies, Boils or Impetigo.*

Scabies	103 cases.
Impetigo following scabies	391 ,,
Boils following scabies	61 ,,
Impetigo and boils following scabies	94 ,,
Impetigo otherwise arising	215 ,,
Boils otherwise arising	94 ,,
Impetigo and boils otherwise arising	42 ,,
	1,000

This analysis shows that scabies was responsible for 64·9 per cent. of all forms of pyodermia and that it caused more than half of the common forms of skin disease in the army.

During the month of April 1917 there were admitted into No. 25 General Hospital 1,786 cases of disease of the skin. Below are summarized some remarks on the record of the diagnosis on admission, the method of disposal, the duration of disease, and the variety of disease present.

In about one-fourth of all cases the diagnosis before admission was incorrect, namely, 453 out of 1,786 admissions. Mistakes occurred principally from confusing seborrhœic eczema with impetigo, and in overlooking scabies. In the first case no worse result arose than delay in cure, but failure to detect scabies was productive of far-reaching consequences because the infected individual remained a source of danger to others as a carrier of disease. It was not uncommon for scabies to be diagnosed and treated as inflammation of the connective tissue, as eczema, as boils, or as impetigo, over periods varying from six weeks to two months. Special reference may be made to three cases. A soldier contracted itch in Gallipoli in December 1915. After a short and incomplete treatment he was returned to duty apparently uncured. He received further treatment in Egypt in February 1916, in December 1916, and at other times. Finally his tent mate was found to be infected, and he was thereupon sent to No. 25 General Hospital. It would appear in this case that active scabies had persisted for one and a half years. The second case was that of a soldier who developed " eczema of the feet." He received treatment in Jersey, Ripon and various places in France during a period of six months. He was then admitted to No. 25 General Hospital, where a diagnosis of scabies was made, which from the history obtained must have been present during the whole period. In the third case the man reported sick with " boils." He was treated at his unit, then at a field ambulance, first for boils and later for septic sores. He was then treated at a divisional rest station, a casualty clearing station and a general hospital, the whole period covering some six months. He was finally admitted to No. 25 General Hospital, where the condition was found to be scabies with secondary furunculosis.

These are undoubtedly extreme cases and should not be taken for common examples of error. They are cited to demonstrate one manner in which scabies was disseminated by means of carriers.

The manner of disposal of the 1,786 cases referred to above was as follows :—

To base details	956	cases.
,, convalescent camp	345	,,
,, venereal hospital	13	,,
,, United Kingdom	472	,,
	1,786	

The men returned to duty directly or through the convalescent camp thus numbered 1,301.

The factors determining the transfer of 472 cases to the United Kingdom were of several kinds, such as urgent evacuation orders, or the severity or chronic character of the condition, or the demand for accommodation.

Excluding those cases transferred to the United Kingdom it was found that an average period of 30·29 days elapsed from the time of admission until the patient was discharged cured. This figure corresponds very closely with a previous estimate of 31·67 days published by Small and MacCormac. It was, however, further elicited that disease had been present for an average period of 31·02 days before admission. Adding together these two figures, a total of 61·31 days is obtained, and this does not take into account the additional time spent, in some cases in convalescent camps, and in all cases in returning to duty. Such figures demonstrate the manner in which one type of "minor casualty" may cause wastage in the army.

As the various types of disease met with during the period under consideration—April 1917—correspond closely with those given in Tables I and II, it is unnecessary to discuss them further. They may be recorded briefly in the following table:—

TABLE IV.

Admissions into No. 25 *General Hospital during April* 1917.

Impetigo	624
Scabies (all but 10 severely infected)	571
Seborrhœic eczema	226
Boils	192
Psoriasis	55
Eczema	34
Herpes zoster	20
Syphilis	13
Ringworm	9
Other skin diseases	42
	1,786

SKIN DISEASES IN THE FORWARD AREAS.

During the winter of 1916–17 and also later, disease of the skin in the forward areas was treated either for short and irregular periods in field ambulances, or regularly and as a special duty in certain units set apart for this purpose. Between 1st January and 16th December, 1916, 11,030 cases passed through one of these scabies centres established in a casualty clearing station of the Second Army.

At the front, as at the base, the cases of pyodermia, which were usually admitted under the heading of "Inflammation of Connective Tissue" (I.C.T.), were chiefly due to parasitic disease. At the front, however, pediculosis played a much greater part in their causation than it did at the base. This may be seen from a study of the following charts.

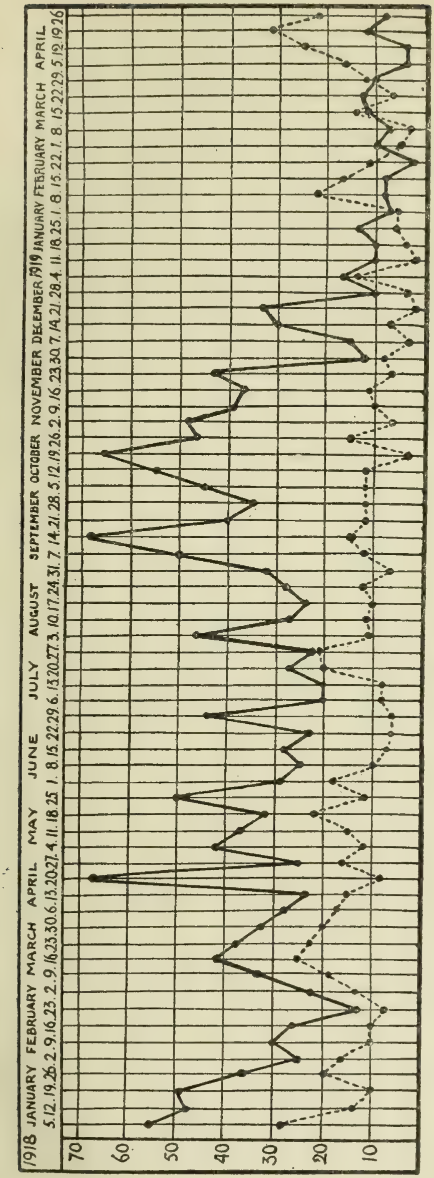

Chart I.—Number of cases of I.C.T. and Scabies admitted to field ambulances of the 41st Division from January 1918 to April 1919. The average strength throughout this period was approximately 14,000. I.C.T.: black line. Scabies: dotted line.

Chart I represents admissions to the field ambulances of the 41st Division from 1st January, 1918, to 26th April, 1919.

It will be noticed that the scabies rate is comparatively steady, which shows that the wastage from that source is fairly uniform despite the conditions under which the troops were working. Rises in the scabies rate generally followed an abnormally low rate, which is probably explained by cases not being sent back to the field ambulances for a short period but being accumulated in their regimental units. Thus the rise on 16th March, 1918, followed a train journey from Italy occupying fifteen days. The rise during February and April 1919, when the division was comfortably housed in Cologne, is due to another cause which will be considered later.

The I.C.T. curve, however, is very variable and one can almost read the history of the movements of the division from it. The curve opens with the division in Italy. The troops had been there nearly two months, but there were practically no arrangements for washing, clean clothes and baths till the middle of December 1917,* a fortnight before the chart begins. The institution of these means of ablution brought a steady fall in the curve lasting till the end of February, by which time it reached a level comparable with that seen in Cologne in 1919. From 1st to 15th March the division was moving by train back to France, and there were no returns ; but on 16th March there was a marked rise, as with the scabies curve, due to accumulated cases. The next three weeks were spent fighting on the Somme during the great retreat and no figures were available ; this was followed by a move to the Ypres sector, where again there was a high return due to accumulated cases. Then follows a period in the line without much fighting till September, showing a moderate incidence. The curve then rises to its highest level during the great advance in September and October, gradually falling from the date of the armistice and during the subsequent march into Germany, and finally reaching a low level on arrival in Cologne in January 1919, where it remains steady.

The temporary wastage from I.C.T. will, therefore, be seen to vary according to conditions, and in that way to differ from the scabies wastage. At its lowest it amounts to less than 10 cases per week for the division, *i.e.*, less than 3·6 per cent. per annum, taking the average divisional strength as 14,000 men. During quiet periods in and out of the line the average is about 30 cases per week, or some 11 per cent. per annum ; while during periods of fighting and movement the figure rises to 60 or 70 cases per week, or some 22 to 26 per cent. per annum.

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* The British divisions had only been sent to Italy during the latter part of November and had scarcely settled down in their new quarters till December.

With regard to this division, the total number of cases sent to field ambulances for I.C.T. for the year 1918 was 1,615, which is a temporary wastage of 11·5 per cent., or more than one-tenth of the division. The number of cases of scabies was 530, or a temporary wastage of 3·9 per cent.

It will be argued that the I.C.T. curve does not represent merely the wastage from the skin complications of pediculosis, and in fact three conditions in addition to pediculosis are commonly included under this heading. Of these the milder forms of trench foot can be practically excluded from this chart, because during the winter of 1917–18 the division was in Italy, while the armistice occurred before the winter of 1918–19. As regards boils, those not due to vermin would be so few as to be unappreciable on such a chart. Lastly, as to minor surgical sepsis, there is no doubt that a proportion of I.C.T. is due to this cause, but from investigation of cases at numerous divisional rest stations under varying conditions this may fairly be estimated at less than one-quarter of the total cases of I.C.T. It is therefore fair to assume that with a deduction of one-quarter, the I.C.T. curve represents the temporary wastage from the skin complications of pediculosis.

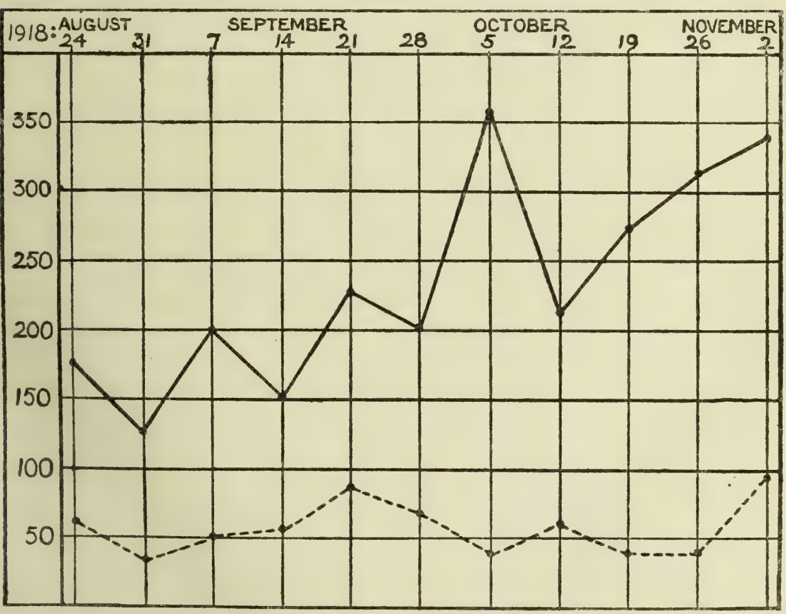


Chart II.—Showing the incidence of I.C.T. and Scabies in the Fifth Army from 24th August to 2nd November, 1918. I.C.T.: black line. Scabies: dotted line.

The persistent dissimilarity of the two curves indicates further that though no doubt errors of diagnosis occurred they may be neglected in drawing the broad distinction between scabies and I.C.T. Some confirmation of these figures is obtained in Charts II, III and IV.

Chart II represents the wastage from the Fifth Army for the three months preceding the armistice. The scabies line is seen to be practically level, while the I.C.T. line shows a medium level during the quiet months of August and the first three weeks of September, followed by a high level during the advance late in September and October.

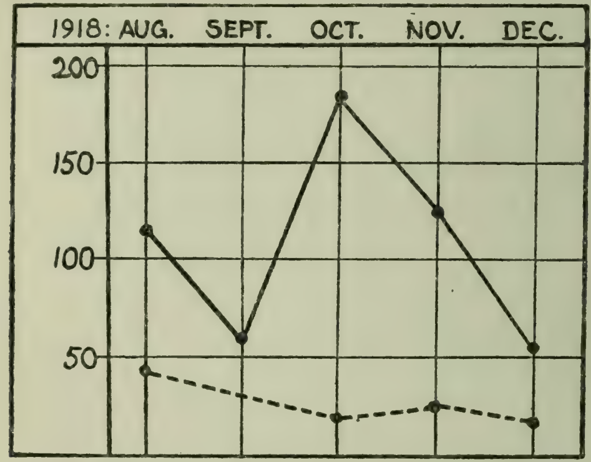


Chart III.—Showing the monthly incidence of I.C.T. and Scabies in the 47th Division for the months of August to December 1918. I.C.T.: black line. Scabies: dotted line.

Chart III shows the same for the 47th Division during the same period and includes the fall during November and December 1918.

Chart IV, from the 59th Division, shows the fall in I.C.T. from October to December 1918, after the armistice, with the steady incidence of scabies apparently quite unaffected by it.

These differences in the behaviour of scabies and pediculosis find their explanation in the method of infection, and the clinical results peculiar to each.

The effects of the *Pediculus humanus corporis* are only occasionally seen in civil life and then usually in old and neglected individuals, chiefly in the casual ward of the workhouse, or occasionally in hospital practice. In the army in the field, however, the body-louse is constantly present, and under conditions when washing and removal of the underclothing become difficult or impossible, practically everyone becomes infested. Infestation may occur by contact with verminous persons whether healthy or sick ; by contact with clothing, bedding and brushes previously used by infested persons ; by contact of clean persons' clothing, blankets and hats, etc. with similar articles belonging to infested persons ; and by infestation through stray lice.

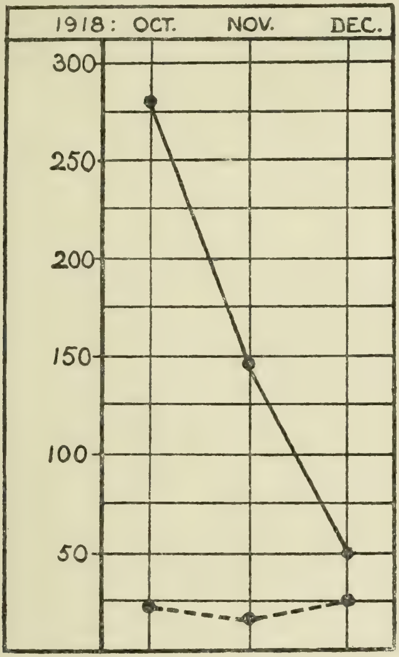


Chart IV.—Showing the monthly incidence of I.C.T. and Scabies in the 59th Division for the months of October to December 1918. I.C.T. : black line. Scabies : dotted line.

Under active service conditions it is impossible to avoid intimate contact of individuals and their possessions. Men lie huddled up together in tents, huts, or dugouts ; their blankets get mixed up, and any clothes or equipment which they remove may lie in contact with those of their neighbour. Further, lice may wander about on the floor, and have even been known to be blown by the wind from one individual to another.

From this it will be seen that once an infested individual is introduced among a number of clean individuals it is almost impossible to prevent the lice spreading to the latter. This, however, is not the only factor in the high incidence in the army, for similar opportunities for infestation occur in civil life among the slum population and yet the skin complications of pediculosis are not common. The explanation of this appears to be that in civil life the underclothes are generally taken off at night and are washed at fairly frequent intervals, so that lice are prevented from breeding to any great extent, while in the field the clothes have to be worn night and day, often for considerable periods of time, and even removal for a short period for washing the body is often impossible. This was pointed out by Leeuwenhock in 1807 and by many observers since that date.

It has further been shown experimentally that lice breed rapidly at body temperature, but not at all below 20° C. (68° F.).

It does not follow, however, that all individuals who become infested with lice, even if heavily infested, develop skin complications, and it will be pointed out later that all the serious skin complications of pediculosis are due not so much to the bites of the louse as to scratching induced by the irritation set up. Hase placed individuals exposed to lice infestation in four groups: persons who are not attacked by lice; those who are attacked continuously and are sensitive to bites; those who, after suffering much from bites, become immune to their effects; and those who have been bitten continuously but do not suffer from the effects.

Of these, the first and last will not develop skin complications, the third group may do so temporarily, but the bulk of the cases will certainly come from the second group. This probably accounts for the fact that even under the most adverse conditions the I.C.T. wastage rarely exceeds a rate of 25 per cent. per annum. It must not be thought, however, that the last group can be neglected, for, although they may develop no symptoms themselves, they are carriers, and therefore a potent source of infection. The third group also, when immunity has been acquired, are an equal source of danger.

To summarize, it will be seen that the introduction of a single infested individual among troops may rapidly lead to dissemination of lice among them; that from the conditions under which they live lice breed readily on all but a small number of insusceptible individuals; that the itching set up by lice leads to scratching of a violent nature with much skin damage, and that owing to meagre washing facilities infection of the scratched skin by pyogenic organisms usually results.

The question of scabies infection is quite a different problem. With lice a whole battalion may be infested, but only a comparatively small proportion requires evacuation. With scabies, every case of the disease, with the exception of an occasional carrier, is evacuated; therefore, a scabies chart directly represents the scabies incidence, but an I.C.T. chart only indirectly represents the lice incidence. The body-louse is a very hardy insect, which travels from individual to individual without difficulty, and may remain alive without food for five to eight days in straw, blankets and the like, while the ova may survive for two or three weeks. With the scabies mite, however, the conditions are quite different.

The life-history and habits of this acarus have been worked out in great detail by J. W. Munro, working in Professor Nuttall's laboratory under arrangements made by the War Office. *Sarcoptis scabiei* var. *hominis* is a very fragile mite. The female lives out her life in a burrow made in the horny layer on certain definite parts of the human body; the habitat of the male is not so certain, but in the pairing stage he is also known to make a small burrow. The eggs are laid in the female burrow and the larvæ inhabit these burrows or make new ones in the surrounding hair-follicles. The nymphs, the intermediate stages between the larvæ and the adults, also appear to make small burrows. It is further found that the acari, both in their mature and embryonic stages, can live away from the body for only an extremely short time, except under such peculiar conditions of temperature and moisture as rarely occur. The eggs, however, appear to be rather more hardy. Munro succeeded in hatching out eggs which had previously been kept at a temperature of 6° C. for periods of from one to six days, while those exposed for seven and eight days failed to hatch. As, however, the eggs are normally hatched in the female burrow, it is not probable that they will often be found in clothing and blankets. Munro has also shown that the acari only exhibit activity when the body and its environments are quite warm. Normally, this only occurs at night, so that casual infection during the day is at least improbable.

Two other points were noted in investigating these cases in the field. First, it was remarkable how large a proportion of infected men had just returned from leave, or come from the base. That this was also the experience of others is shown by the numerous official letters from front line units complaining of men being sent up from base depots with scabies. A striking confirmation of this occurrence is observed on Chart I. A considerable rise in the scabies rate occurred in February and April 1919, when the division concerned was comfortably settled in Cologne and when the I.C.T. rate had fallen to its lowest level; in fact, those are the only two occasions when the scabies rate had exceeded the I.C.T. rate during the period of the chart. Now this rise in scabies occurred not only in this particular division, but throughout the whole of the Second Army on the Rhine. Chart V shows the rise in scabies incidence in it from January to March 1919. There were probably two factors to account for this rise. During this period a number of " young soldiers' battalions " were sent over from England and brought a great deal of scabies with them. Out of 410 cases of scabies admitted to the Army Scabies Centre for the fortnight ending 22nd March, 1919, 147 cases came from these battalions, which constituted only about one-tenth of the army. But even when these were excluded there was still an abnormally high incidence among the remainder of the army which can only be attributed

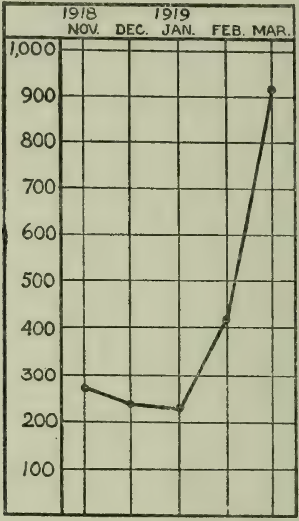


Chart V.—Showing the incidence of Scabies in the Second Army from November 1918 to March 1919 (inclusive).

to infection from the civil population. There is no doubt that the scabies rate frequently rises with the venereal rate, and in this case it certainly was so.

The other point that came under observation was the incidence of lice and scabies in the prisoners of war camps in the devastated areas. Chart VI was prepared from figures obtained from Lieut.-Colonel R. W. Hunt of admissions from certain of these camps to No. 42 Casualty Clearing Station at Douai.

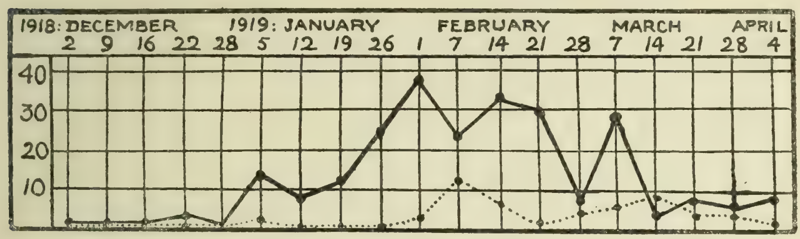


Chart VI.—Cases of Pediculosis and Scabies admitted to No. 42 Casualty Clearing Station from Prisoners of War Camps. The number of prisoners of war in camps which sent their sick to this C.C.S. increased gradually from 400 in December 1918 to 1,500 in January 1919, 2,800 in February and 4,000 in March. Pediculosis: black line. Scabies: dotted line.

From the time of the armistice onwards German prisoners of war were drafted from large base concentration camps into camps of about 400 men each, in the devastated areas in France. They were mostly verminous when they arrived, and as practically no provision had been made for washing, supply of fresh clothing, or delousing in the new camps, the sick wastage from verminous skin diseases became unusually high.

It will be noticed that the curve of lice pyodermia rose steadily until in February it remained more or less stationary, when as a result of vigorous measures it fell even more rapidly in March. The incidence here is far greater than anything that was seen in the army; at the height of the epidemic it averaged about 30 cases per week out of a strength of about 3,000, which is equivalent to about 50 per cent. per annum, or nearly twice the amount met with in a division under the most unfavourable conditions.

The scabies curve does not follow the lice curve at all; there are two well-marked rises, both occurring on the opening of new camps, and the tendency is for the curve to fall again when these cases have been dealt with.

These remarks suggest that scabies is not transmitted much in the forward areas but is largely introduced from outside. Certain experimental work done by Munro on the transmission of infection must not, however, be overlooked. He found in a hospital in England that scabies could be transmitted by the wearing of infected pants and shirts, and he also showed that infection could occur by sleeping in infected blankets. Yet infection only occurred twice out of a number of exposures, and the conditions were quite different from those of the army front.

Two other points require mention. Munro has shown that infection can be easily transmitted by infected gloves, and to this he attributes the comparatively high incidence among officers of the Royal Air Force.

Also a certain number of persons must be classed as carriers. These are people in whom the acarus causes little or no itching and whose condition is therefore overlooked. They are quite common in civil life and they should be looked for on active service as a possible source of danger.

SCABIES.

The mode of spread of scabies differs considerably from that of pediculosis, as the life history and habits of the itch mite differ from those of the louse. In scabies, as is well known, the impregnated female forms a tunnel beneath the skin in which the eggs are laid and from which she never emerges. The body-louse, on the other hand, wanders freely, and is therefore easily transferred from one individual to another. The ova are deposited on clothing, and also on the pubic and axillary hair, although this was not known before the war.

To acquire scabies prolonged and intimate contact with an infected person,or infected material such as blankets or clothing, is essential. On the other hand, the louse can crawl from man to man without much difficulty, and the process is favoured by the conditions of trench life. Insects may also become detached and get upon straw or bedding, thus increasing the chance of infestation. In pediculosis the ova are present on garments, wherefore more elaborate methods of disinfection are required than in the case of scabies, where the ova remain on the individual.

That the louse can easily transfer itself from one individual to another under the crowded conditions of trench and camp life requires no proof. It may be less readily believed that in scabies a similar process did not occur. Neither in No. 25

nor in No. 26 General Hospital was any attempt made to separate patients with scabies from patients with other skin diseases. They lived together in the same wards and tents, used the same baths, and followed a similar mode of life. Despite this, cross-infection did not occur.

Such being the case, it may be asked by what means was scabies disseminated in the army in France. Small and MacCormac have pointed out that the chief sources were blankets and underclothing, " mangy " horses, and infected women. Men coming out in drafts from the United Kingdom were given blankets previously used by others, in passing through camps or when they reached their unit. Thus blankets provided a common medium capable of satisfying all the conditions essential for infection. Horses with " mange " may at times contaminate men, and a probable instance of this came under the observation of Captain Small. At one period a number of men were admitted with scabies in an R.A.S.C. unit. The source of the epidemic was not discovered until an examination was made of the horses, a number of which were found to be suffering from parasitic mange. On their removal and treatment the epidemic ceased.

French authorities have laid much stress upon the venereal origin of the disease ; but careful investigation indicated that this was not an important method of infection in the British army in France during hostilities.

Diagnosis.

As seen among soldiers during the war, scabies differed from the type usually met with in civil practice, and for this reason many cases escaped detection. The hands and wrists were often spared and the characteristic burrows were rarely observed.

While a diagnosis might be made in two ways, either by observation of the distribution of the lesions, or by discovery of the causal parasite, the latter method was impracticable under conditions of active service. Nor was it necessary, for the lesions were arranged in so characteristic a manner as to be pathognomonic.

In uncomplicated scabies the eruption, consisting of papules, vesicles or burrows, *i.e.*, tiny sinuous or angular black lines, was found on the anterior axillary folds, the abdomen, the wrists, between the fingers, or sometimes on the ankles and feet. The penis was affected in nearly every case, papules or impetiginous lesions forming on the mucous membrane or skin. After a certain time impetigo and sometimes boils appeared—the period of secondary pyodermia. The distribution was equally characteristic, for the impetigo, even when widely spread, became grouped over the lower buttock triangle, the elbows, and the knees. In this stage the primary condition might be easily overlooked and such cases provided the majority of "carriers." The possibility of scabies had, therefore, always to be considered in every case of extensive impetigo or furunculosis.

Scabies had to be distinguished from pyodermia, pediculosis, pompholyx and syphilis. From pediculosis the diagnosis was made by the distribution and by the absence of the characteristic lesions of scabies on the hands, wrists, and penis. Nevertheless, as will readily be believed, the two infections not infrequently co-existed. The vesicular eruption of pompholyx at times presented some difficulty, but the vesicles were more deeply seated and were chiefly limited to the hands and feet. A large single scabid penile lesion might at times suggest syphilis. A differential diagnosis was not always easy, especially where scabies was of venereal origin; both diseases might be found in the same individual.

Treatment.

The principles underlying the treatment of scabies included first, the exposure of the parasite and ova, secondly, their destruction by a suitable parasiticide, and thirdly, disinfection of contaminated articles of clothing and bedding.

Of all remedies, sulphur is generally acknowledged to be the most efficient, and by reason of its procurability and cheapness it was specially suited for the extensive requirements of the army.

During the war many preparations of sulphur were tried. After experiment the old-fashioned plan of inunction with the B.P. ointment was found to be the most satisfactory, although good results were obtained with sulphur in other forms, such as Vlemingkx's solution. Reference may be made to the "sulphur vapour treatment," for it obtained a certain vogue. A number of instances of the after results came under observation. It proved an unsatisfactory and unreliable form of treatment; cure was uncertain, and severe secondary dermatitis common.

The treatment of scabies as adopted by MacCormac may be outlined as follows. On the first day the patient was thoroughly rubbed with soft soap for fifteen minutes. He then entered a warm bath where he lay for twenty minutes ; during the last five minutes the infected sites were gently scrubbed with a soft brush. This procedure was designed to open up the burrows and expose the acari and ova. Steam or shower baths could not accomplish this satisfactorily and were therefore unsuitable. After drying, a liberal quantity of sulphur ointment (B.P.) was rubbed over the whole body below the neck, special attention being paid to the hands, feet, and penis. This inunction was repeated on the second and third days. On the fourth day, but not before, the patient was given a second bath and supplied with clean clothing and bedding. Such articles as socks, wrist straps, gloves, and the string of identification discs also required disinfection.

This routine procedure was successful in the vast majority of cases. Occasionally, it caused some degree of dermatitis, a condition easily allayed by simple ointment or dusting powder. This dermatitis was of importance ; it usually made its first appearance five to seven days after sulphur treatment had been completed and was associated with itching, and therefore occasionally led to the false conclusion that relapse had occurred.

It should be noted that the preliminary bath was solely intended to expose the parasite and ova, therefore no disinfectant had to be added. In applying the sulphur preparation the whole body below the neck had to be treated, otherwise a few insects might escape destruction, with consequent re-infection. The sulphur ointment was employed on three days only ; further application was unnecessary and might cause severe dermatitis. Finally, unless all contaminated material was disinfected, relapse was probable.

In 1918 a pamphlet on scabies was issued to the army. While it represented the result of much careful investigation reference may be made to it since it differed in certain respects from what has been said above. Moreover, dermatologists will hardly concur in the recommendation that the parasiticide liquor calcis sulphuratæ should not be allowed to run on to the glans penis. This was a region very commonly found to be infected and therefore required special attention in treatment.

The severe type of scabies commonly met with in France required 31·7 days for cure as against three days for the average early case. But these severe types were in themselves evidence that disease had been present for a considerable time during which the infected man was capable of contaminating others. Early detection, therefore, not only shortened the period of treatment but also served as a means of preventing the spread of disease. Such early detection demanded first, familiarity on the part of the medical officer with the prevalent and unusual type of scabies ; and secondly, the provision of sufficient opportunities for complete inspection. Early treatment was complementary to early diagnosis and was of equal importance. It has been shown that 30·29 days elapsed before a man affected with skin disease reached the base. Where treatment was carried out near the front area this figure was reduced, but, on the other hand, the more accessible the unit the less adequate must the means of treatment be unless this duty was undertaken specially. The provision of scabies hospitals for each army corps would seem to satisfy all requirements under conditions of active service, for they would afford early and skilled treatment, thereby both shortening the period of treatment and limiting the opportunities for spreading infection.

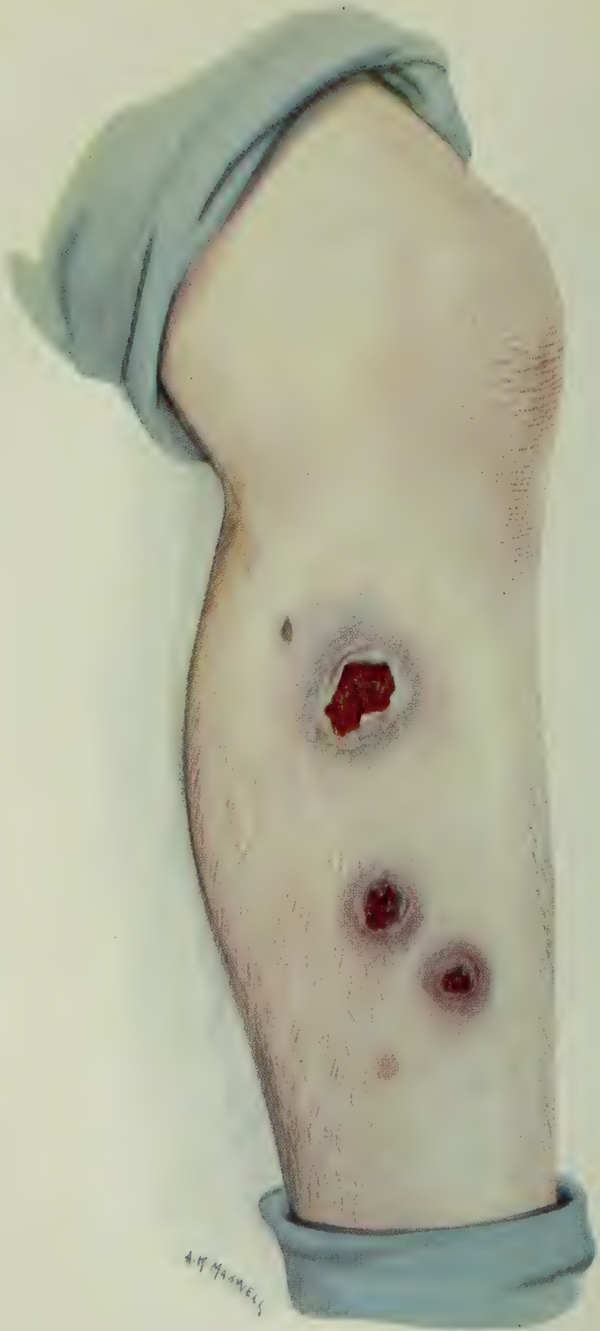
As has been pointed out, scabies may be spread directly from infected women or horses, or indirectly through contaminated blankets and clothing. The latter method was considered to be the chief means by which the disease was spread in the army. Systematic disinfection of blankets was, therefore, of considerable importance in controlling the disease.

THE IMPETIGO GROUP OF SKIN AFFECTIONS.

The conditions included under this heading provided the largest number of cases of skin disease admitted into medical units. As is well known, impetigo results from a streptococcal infection of the skin. While often primary it may also be secondary to some other condition, such as scabies and pediculosis. Besides these forms, an impetigo may be grafted upon some other dermatosis, especially seborrhœic eczema, a process known as impetiginization. The facts allow of the division of the impetigo group into four classes : (1) impetigo contagiosa ; (2) ecthyma, or deep impetigo ; (3) impetigo secondary to scabies ; and (4) infected (impetiginized) seborrhœic eczema.

Impetigo contagiosa is commonly met with in civil hospital practice and among the poorer classes of the community. The primary lesion is a bulla, which is soon replaced by the typical " stuck on " crust. Occasionally the primary lesion persists throughout, constituting the bullous form of the

PLATE I.



Healing Ecthyma of Leg.

disease. The lesions are found on the face and hands chiefly, parts of the body accessible to external infection. Contrary to what might have been expected, this form of the affection, if impetiginized seborrhœic eczema be excepted, was uncommon among the troops.

The treatment was simple, the crusts were removed by boric starch poultices, or fomentations, or by mechanical means, and the sores were dressed with 1 per cent. ammoniated mercury in zinc ointment.

Ecthyma is a deep or dermic impetigo, differing only in degree from impetigo contagiosa. In its fully developed form the lesions consist of shallow crusted ulcers with undermined edges and purulent contents. Surrounding each lesion there was a bright erythematous halo, the vividness of which furnished a useful indication of the activity of the process. (Plate I.) To this condition, in common with boils, cellulitis and various forms of pyodermia, the diagnosis "I.C.T." was commonly applied in the army. Although ecthyma might be primary, the great majority of cases were secondary to scabies or pediculosis. It proved a very real cause of disability, especially in its more severe forms. The ulcers were slow to heal and left behind pigmented scars and occasionally papillomatous lesions. The treatment was difficult and prolonged as compared with simple impetigo. Fomentations during the acute phase served the purpose of assisting the flow of antibodies to the part, and promoted drainage. When the more acute stage had passed, as indicated by a fading of the surrounding halo, antiseptic dressings, such as eusol, flavine, or perchloride lotion, were used; finally, dressings of 1 per cent. ammoniated mercury, preceded by a painting of the sore with 3 per cent. silver nitrate solution, were employed.

Reference has already been made to impetigo following scabies. The impetiginous lesions formed groups over the lower buttocks, elbows, and knees, a distribution noticeable even where the eruption had become widely spread. It was generally found advantageous to treat the causal scabies first and then to employ the methods described above for the secondary ecthyma.

The last class is that of infected or impetiginized seborrhœic eczema. During the whole course of the war a peculiar disposition to eruptions of a seborrhœic type was manifest. Not only was the incidence of seborrhœic eczema unduly high but the skin became peculiarly sensitive, being easily affected by slight degrees of trauma. Thus the application of sulphur ointment, even when limited to three days, was frequently followed by dermatitis, a result unusual under ordinary conditions. Often the dermatitis attributed to sulphur was present before its application and was due to the irritation and scratching associated with scabies or pediculosis.

In its characteristic form this seborrhœic process was seen as an eczematous eruption involving certain sites, by choice the scalp, beard and moustache regions, or the flexures such as the axillæ or groins (Fig. 1). The resulting moist surfaces were prone to streptococcal infection, and the combination of this with the eczema produced on the face and head a condition so closely imitating impetigo contagiosa that it was frequently mistaken for it. A distinction could be made by observing that the crusts were not merely " stuck on " as in the case of impetigo contagiosa, but were more firmly attached to the underlying skin and on removal left an irregular surface behind. The distribution also was different.

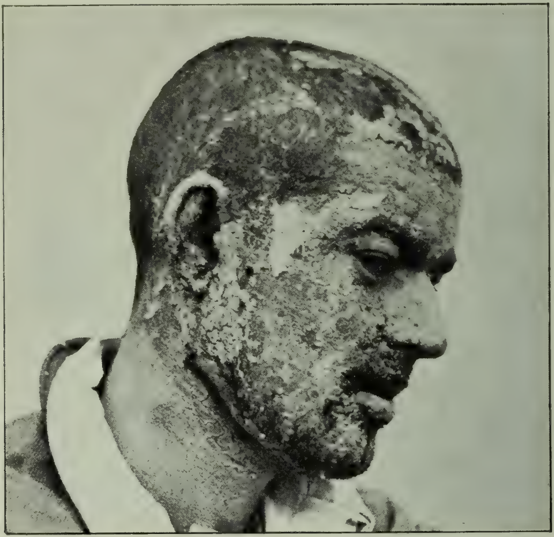


Fig. 1.—Illustrating infected or impetiginized seborrhœic eczema.

When the head and face became severely involved the disease usually spread to the ears and into the meatus, giving rise to a purulent discharge similar to that met with in middle ear disease. The history of the two conditions served to differentiate them. In the case of eczema the discharge followed the eruption; in middle ear disease the discharge appeared first, the impetigo later.

The best proof that the condition described was what may be termed an impetiginized seborrhœic eczema lay in its response to treatment. Dealt with as an eczema, it got well, but when mercurial ointments were used the condition became aggravated.

Of the various methods of treatment tried for this condition, none proved so successful as calamine liniment, the formula of which is as follows :—

Calamine	gr. xx
Zinc oxide	gr. xv
Lime water	dr. ii
Olive oil	oz. i

To bring the remedy into close contact with the affected skin, a preliminary removal of all crusts by boric starch poultices or fomentations was essential. Neglect of this might considerably prolong the duration of disease.

DERMATITIS FROM MUSTARD GAS.

Skin eruptions from mustard gas were not seen until the later stages of the war when this substance was first used. The effects were not unlike those resulting from the application of chrysarobin. The flexures, face, and scrotum were especially involved, the degree varying from slight erythema to severe burning with vesication of bullous formation. Secondary invasion with pyococci was not uncommon, especially in the latter type. For the average case admitted to hospital applications of boric acid ointment were found most suitable. When infection had occurred the usual surgical methods were employed.

PEDICULOSIS.

The skin lesions caused by pediculosis and their treatment require special consideration.

There are three varieties of lice which attack the human body; two of these, namely, the *Pediculus capitis* and the *Pediculus vestimentorum* (or *corporis*),* appear to be merely forms of the same species, *Pediculus humanus* Linnaeus; while the third, the *Pediculus* or *Phthirus pubis*, Leach, is a separate species.

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* A new nomenclature has been given to *P. capitis* and *P. vestimentorum*, the former being now named *P. humanus humanus* and the latter *P. humanus corporis*.

Of these three varieties the *Pediculus vestimentorum* is the one which was responsible for nearly all the sick wastage in the army, *Pediculus capitis* being of no consequence at all, while the *Phthirus pubis* was comparatively rare.

The *Phthirus pubis* lives chiefly on the pubic hairs, but may also involve those of the perineum, thighs, abdomen, chest, and axilla, and in rare cases the beard and eyelashes. In the majority of cases it is, however, limited to the pubic area, and for that reason the symptoms produced by it are confined to that area. As far as the army is concerned, infection by it is almost always contracted during venereal intercourse, though the possibility of infection occurring from a latrine seat cannot be altogether excluded.

There are two common symptoms, itching and the presence of small bluish stains on the skin. The itching is often intense and may lead to sleeplessness, but is localized to the areas attacked. In spite of its intensity scratch lesions are seldom seen and consequently sepsis of the skin is rare; both do, however, occasionally occur. The irritation is due to the bites of the insect and the injection into the bite of its irritating saliva. The bluish stains found on the skin in regions infected by the crab-louse are now known to be produced by the bites of that insect. They are probably due to the action of the saliva on the blood at the site of puncture. They are 4 to 10 mm. in diameter, not raised above the skin, and do not disappear on pressure. They have been known as *maculæ cæruleæ* or *taches bleuâtres*. During the war on several occasions they led medical officers to suspect typhus fever.

The *Pediculus vestimentorum* is about 3 mm. long when fully grown, of a transparent appearance except after feeding, when it is of dark brown colour owing to the blood in its stomach and intestines. It can travel with great ease and freedom on almost any surface. It normally lives in the clothing, provided a certain amount of warmth and moisture is present, and comes on to the body to feed. When an infested person is stripped, however, few if any lice are found on the body itself. Its eggs are normally laid on the clothing, especially in the folds or seams; one of the most favourable sites for lice to breed in is the pleats of the Highland kilt around the waist. Semon and Barber have pointed out that eggs are sometimes laid on the body hairs, a fact which had also been noted by previous authors but had been more or less overlooked. This, however, seems to occur only in heavily infested individuals.

It is obvious from the above remarks that lice occur in the largest numbers on those parts of the clothing which are in most intimate contact with the skin, for there they obtain most warmth and also have the least trouble in feeding. This fact is of much importance in determining the distribution of the skin lesions caused by the pediculus.

The main symptom produced by the body-louse is itching, and this is limited to the areas bitten. In lightly infested individuals these areas are localized and well defined, but in patients heavily infested they are more or less generalized. The itching, as in the case of the *Phthirus pubis*, is produced by the injection of irritating saliva into the puncture made by the insect. Tiny red papules are produced at these spots. These lesions, however, are insignificant in comparison with those produced by the violent scratching that follows them and, unlike scabies, the scratch lesions are not localized to the irritable spots.

As mentioned above, the areas most bitten are those which are in most intimate contact with the clothes. In the soldier there are three well-marked areas: the shoulder area, which includes the top of the shoulders, the upper scapular region and the upper part of the chest nearly down to the nipples; the waist area, which includes the back from the level of the lower dorsal spines down to the gluteal folds, the loins, the hips, and the abdomen; the puttee area, from the knees to the ankles, and in those who wear riding breeches up to the middle of the thigh. This localization is seen in the less severe cases; in severe cases the whole of the covered area of the body is affected. The lesions consist in the milder cases of small crusted follicular papules and linear excoriations. The follicular papules are chiefly produced by tearing the tops off the follicles when these have been erected by the contraction of the arrectores pilorum muscles in reaction to the stimulus of scratching, though some may be produced by the bites of the lice. The crusts on these papules are usually blood-stained. The linear excoriations are simply blood-stained thin lines produced by the finger-nail. In some places these scratched papules become surrounded by an inflammatory zone, and as a result of the congestion more fluid is brought to the lesions, weeping ensues and a condition of eczema results. The fluid from these lesions becomes infected with pus-forming organisms, and inoculation of this, by further scratching, may produce lesions of impetigo contagiosa or further eczematous lesions.

The true impetigo lesions begin as blebs of clear fluid with a very thin wall; they are rapidly ruptured and the fluid dries to form thick crusts. The skin under these crusts may ulcerate, especially if much damaged by scratching or if the patient is much debilitated, and an ulcerating impetigo or ecthyma develops. The ecthyma which is the common accompaniment of severe cases of pediculosis is not, however, usually caused in this way. There are two forms commonly met with. The first is a circular ecthymatous lesion which, as is pointed out by Semon and Barber, generally originates in a pustule or boil; and the second is a linear gutter-shaped ulcer, which is undoubtedly produced by violent linear scratching.

The ordinary boil is another form of lesion which is not uncommon. It is not quite clear how these arise, whether from an infected hair-follicle or from an infected louse bite; Semon and Barber favour the latter view. One thing, however, is clear, that this is the one type of lesion which tends to recur long after the original cause has been removed, and it is difficult to avoid the conclusion that the ætiology of these boils is the same as of those which occur in persons not infested with animal parasites, namely, a staphylococcal folliculitis.

The linear ulcer can be seen in process of formation. At first a series of petechial hæmorrhages is seen in the scratched area; these on further scratching run together, an abrasion of the surface is made, pus organisms gain access to the damaged tissue and the whole breaks down, leaving a gutter-shaped ulcer which exudes pus. In most cases this latter dries in the form of a crust, but pus can usually be squeezed out from under it, and finally, when the ulcer heals, it leaves behind a deep pigmented scar. Linear ecthyma generally begins on the legs and eventually may involve thighs, buttocks, back and upper limbs. There is little doubt that itching is most intense on the legs and this is probably due to circulatory stasis and to the heat of the puttee.

Pigmentation is also common after other less destructive lesions, the pigmented body of the louse-infested individual in civil life being well known and constituting the so-called "vagabond's disease."

Apart from the skin lesions, the effects of pediculosis on the individual may be very marked. Prolonged scratching and loss of sleep, coupled sometimes with the discomforts and hardships of life in the trenches, may produce loss of weight, debility and neurasthenia. Fever is said to be produced by the bites of lice even in the absence of pyogenic infection.

Diagnosis.

The only condition likely to be confused with pediculosis under active service conditions is scabies, and the difficulty of diagnosis is increased by the fact that both diseases not infrequently occur together. The diagnosis should, however, be easy in the majority of cases.

It has been pointed out above that the lesions of pediculosis are most marked over the shoulders both back and front, around the waist, including loins and hips, buttocks, and between the knees and ankles, though the thighs are frequently involved also. The lesions are scratched papules, linear excoriations, eczematoid patches, impetigo, circular and linear ecthyma, and boils.

In scabies the distribution is quite different; the scratch eruption forms circles around the sites of election of the female for her burrow. The sites are the genitals, penis and scrotum, the gluteal cleft, the anterior (rarely the posterior) axillary fold, the elbows, the fronts of wrists, ulnar border of the hand, webs and sides of fingers, fronts of knees, and dorsum of feet. The scratch eruption, therefore, occupies the front of the body from the nipples to the knees, the anterior axillary fold, the back of the arm and forearm in the region of the elbow, the front of the forearm in the region of the wrist, the lower part of the buttocks and inner aspect of thighs, the fronts of the thigh and leg in the region of the knee, and the dorsum of the foot and front part of the ankle.

Thus, except in very severe cases, the whole of the back escapes in scabies, except for the lower part of the buttocks and upper part of the thighs, whereas it is markedly affected in pediculosis. The front of the chest above the nipples escapes in scabies, but is scratched in pediculosis. The bulk of the leg escapes in scabies, but is much affected in pediculosis. Further, wrists, forearms and hands are frequently affected in scabies, but not in pediculosis.

The types of lesion, too, are different. In scabies they are chiefly scratched follicular papules; linear excoriations are hardly ever seen. Impetigo and eczematization are more common and better marked in scabies than in pediculosis. Ecthyma rarely occurs in scabies, except in the gluteal fold and its immediate neighbourhood, and is of the circular type and smaller than in pediculosis. Linear ecthyma never occurs in scabies alone. Boils may occur in both conditions but are more common in pediculosis.

To these variations in the site and character of the lesions must be added the presence of the typical acarine burrow, the occurrence of papular lesions associated with it on such sites as the glans penis, and the discovery of the female acarus in a burrow.

Treatment.

The first essential is to remove the cause. Once the cause is removed the milder, non-septic cases get well rapidly with the application of lead or calamine lotion.

Many methods have been advised for the treatment of pubic phthiriasis. The best results have been obtained from clipping short the hair of the affected parts, a more comfortable process to the patient than shaving, and rubbing in a 5 per cent. β-naphthol ointment night and morning for two or three days. Semon and Barber recommend repeated applications of paraffin, 1 in 40 carbolic acid lotion, or, better still, petrol. Gunn recommends naphthaline and sulphur, 1 per cent. of each in petrol. All these methods are effective. The older treatment with ung. hydrarg. is better avoided as it not infrequently leads to a dermatitis.

In phthiriasis, due to the body-louse, eczematized patches, if not very septic, should be treated for a few days with applications of calamine lotion and, after the acute stage has subsided, calamine liniment. Liniment. calam. (B.P.C.) or Lassar's paste should be applied. If this does not clear up the patches, and provided no trace of sepsis remains, they should be painted with crude coal-tar, which is allowed to dry, and a talc powder dusted over the surface. This coating should be renewed for about a week and then allowed to come off, when recovery should have taken place.

For impetigo contagiosa lesions the crusts should be removed and a paste of hydrarg.-ammon. gr. xv, past. Lassar ad. ℥ i. applied. If this does not heal the lesions they should be dressed for a day or two with 1 in 1,000 acriflavine lotion and the paste applied again. Extensive cases of impetigo should be given warm baths and the crusts allowed to soak off. After this they can be dressed as described above.

The ecthymatous lesions are the most troublesome. Ecthyma cases, if the lesions are at all extensive, are not suitable for treatment in forward units and should be evacuated either to stationary hospitals in the army area or to the base. The crusts should be removed by lysol baths, bathing, or, if necessary, starch poultices and 1 in 1,000 acriflavine compresses until pus formation ceases. During this time patients should be kept in bed. Thereafter the lesions on the limbs should be bandaged up with Unna's paste dressings, and after a day or two the patient can be allowed up. These dressings should be changed every two days at first, the intervals being lengthened as the discharge diminishes. The advantage of this dressing is that it splints the parts, and forms an occlusive protection against the friction of the clothes, and also against the patient's fingers. On the trunk and buttocks Unna's paste is difficult to apply and it is better to use the mercury–Lassar's paste, noted above, spread on lint and fixed with triangular bandages These lesions on the body, however, are less troublesome than those on the legs. MacCormac recommends painting the lesions with a 3 per cent. solution of silver nitrate in spirit of nitrous ether, as noted above.

The treatment of these ecthymatous lesions of the legs does not, however, end with the healing of the ulcer. They are extremely liable to break down again if the man is sent back to duty too soon. Such patients require several weeks' graduated exercises at a convalescent camp, and should not be sent for active trench duty for at least two months after the lesions have healed. The heat of the puttees is liable to set up itching again, and these should at first be worn only for short periods at a time.

The most troublesome cases are those with boils. They tend to become recurrent even when the cause is removed. Constitutional treatment is here necessary, the patient should be carefully overhauled and anything tending to lower the general health rectified. The occasional association of boils with glycosuria must not, however, be lost sight of. Rest and careful dieting with iron and arsenic internally, together with local treatment, will often suffice, while other cases do well on sulphur administered internally either in the form of ichthyol, ♏v (in capsules), thrice daily, or calx sulphurata, gr. i, in pill, thrice daily. Staphylococcus vaccines are successful in some cases, while others respond well to intramuscular injections of collosal manganese, 0·5 to 1 c.c., given every second or third day for three or four injections. Stannoxyl, a proprietary preparation of oxide of tin, in doses of four to eight tablets a day, by the mouth, is also occasionally useful in resistant cases.

Locally the larger boils should be treated surgically by excision or incision and scraping ; with the smaller boils this is seldom necessary. Boric acid fomentations should never be used, as they tend to spread the infection, but 1 in 4,000 perchloride of mercury is less open to this objection. Early boils should be painted with tincture of iodine. Baths should be given frequently in all cases but should not be too hot.

The local treatment is of less importance than the general treatment in these cases, the main point in local treatment being to keep the skin clean and to deal surgically with the local lesions when they appear.

The preventive treatment of scabies and pediculosis resolves itself into the steps taken to prevent verminous infestation of the troops.

ORIENTAL SORE (DERMAL LEISHMANIASIS).

Dermal or cutaneous Leishmaniasis was previously known as Baghdad boil, Aleppo sore, frontier sore, Delhi sore and, more commonly, oriental sore. It is endemic in many countries—Mesopotamia, Persia, Palestine, Afghanistan and, to a lesser extent, in Egypt and the Sudan—where British troops were fighting. It is not unknown in Europe. The subject was, and is, of interest to medical officers stationed abroad, and reports on the ætiology, distribution and treatment of oriental sore have been published in medical journals from 1839, and in Army Medical Department Reports from 1860 onwards.

Many have investigated the disease, but it was chiefly the work of Leishman, Wright, Rogers, Nicolle, Statham, Firth, Wenyon and Patton, which previous to 1914 assisted medical officers to form clear ideas on the clinical varieties met with, to recognize *Leishmania tropica* as the cause of the disease, and to realize that the organism was probably conveyed by a biting insect. It was also established that the number and size of sores on each individual varied, that they usually developed during the cold weather, and that they were situated on exposed parts of the body. The following distribution was noted in 300 cases: face, 60; neck, 12; trunk, 0; upper arm, 6; elbow-joint, 42; forearm, 30; hand, 78; thigh, 0; knee-joint, 36; leg, 24; foot, 12.

Statements concerning the disease which appear in ancient stories of adventure are rarely accepted by modern scientists, but readers of "The Adventures of Hajji Baba of Ispahan" will recall his description of Baghdad boil, his opinion on its incidence, and his fair nurse Dilaram who treated his sore. It is of interest, therefore, to record that in 1874 the late Major-General Sir J. H. Evatt, when a young army surgeon, repeated in an official report Hajji Baba's legend that everyone proceeding to Baghdad contracted the disease within one year of their arrival in the country, and Wenyon restated this in 1911.

The British armies in 1913 had only 53 cases of oriental sore. It is interesting to consider how this disease affected them in endemic areas during the war where all the predisposing factors were present—a cold season following a warm season, myriads of biting insects everywhere present, the troops for the greater part of the year clad in shorts and shirts which left their face, neck, arms, hands and knees exposed—and how medical officers investigated the problems connected with it.

It was not until December 1916 that the Director of Medical Services in Mesopotamia issued a memorandum on Baghdad boil. As is known, the sores may take months to develop after the date of infection. It must be presumed either that there had been no great number of cases in the forces, that the condition had not always been recognized, or that the affected persons had been evacuated before the typical sores developed.

The records of one division, which was organized in Mesopotamia in 1916 and was stationed in Nasiriyeh on the Euphrates, state that 20 cases were reported by December 1916 and 137 new cases by March 1917. The division was composed of units which, with one or two exceptions, had not been in the country more than a few months. Medical officers in the division had no doubts about the diagnosis, as Lieutenant P. B. Naidu, I.M.S., had demonstrated the *Leishmania tropica* in one case, while Lieut.-Colonel T. B. Kelly, I.M.S., who had worked on the subject on the Indian frontier, and Major Patton, I.M.S., who had investigated the disease at Cambray, India, were commanding medical units in the division.

The A.D.M.S. of the division showed the early cases to the members of the Medical Advisory Committee who visited the area in December 1916. One of the members of the committee was Colonel Wenyon, who had previous to the war investigated the disease at Baghdad. The committee agreed with the diagnosis, confirming Lieutenant Naidu's finding of the *Leishmania tropica*, and considered it advisable to forward a memorandum to the director of medical services on the ætiology, prevention and treatment of oriental sore. Lieutenant Naidu was detailed to continue his studies of the condition, and a comprehensive survey of the disease at Nasiriyeh has been obtained from his reports, which cover a period of four years.

Patton, Acton and others continued to study the ætiology of the disease, and Cooper, Cope, Ormerod, Evans, Sen, Norman and Harries turned their attention principally to the different methods of treatment which had been recommended at one time or another.

Complete figures are not available at present, but assistant directors of medical service of the bases on the lines of communication noted that dermal Leishmaniasis was very prevalent throughout Mesopotamia at certain periods, and four thousand odd sores were examined for *Leishmania tropica* during two and a half years' work in the laboratories.

At No. 31 British General Hospital, Baghdad, 29 out of a total of 140 medical personnel developed typical sores. When it is remembered that many formations had no opportunities of obtaining laboratory assistance in diagnosing cases, that many cases were treated regimentally, and that the evacuations for sickness from the Mesopotamia Force were very great, it may be presumed that the total number of cases in this force alone numbered 10,000. The greatest number of cases were reported in November, December, January, February and March; the fewest in May, June, July and August; while April and October furnished an intermediate number of cases. It was found that the incidence was higher among units when stationed in towns along the banks of the Tigris and the Euphrates than when they were stationed in the desert.

The situations of the lesions noted by previous investigators were confirmed, but Naidu observed that among the British troops single sores were oftener the exception than the rule, and he drew attention to the number of sores amongst Indian troops, which were situated on the shoulder, upper arm, body, abdomen, loin, buttock and thigh. Acton, in an analysis of 517 cases occurring among British and Indians at Amara, gave the distribution of the cases as follows: head 108, arm 262, trunk 10, and leg 137, and pointed out that the sores were usually situated on thin, hairless areas of the skin.

Only two sores were met with on the scalp, and in both cases the men were practically bald. The mucous membrane of the lips and the junction of the skin of the lip and mucous membrane were sometimes affected.

The house-fly and stomoxys, the human louse, the bed-bug, the mosquito and the sandfly have all been considered vectors.

Wenyon had demonstrated that the parasite is unable to enter through the unbroken skin, and is incapable of surviving on the skin surface. He found that to produce the disease a breach in the continuity of the skin was necessary, and that infection could only take place from person to person through some pre-existing abraded surface. He suggested that the house-fly could convey the disease from one person to another, but did not believe that this was the only method of conveyance, and thought that transmission was more probably due to the bite of another insect, for example, the mosquito or sandfly.

Naidu reported a case where his assistant was infected by a fly passing from an open typical sore to a small razor cut on his face. A typical sore developed on the site of the cut in a fortnight.

The stomoxys bites through clothing, and Ormerod observed that its bite was followed very frequently by the formation of an oriental sore at the site of the puncture. Acton and Naidu failed to confirm this, although observations were made when oriental sore was prevalent in the Amara and Nasiriyeh areas.

Lice were not prevalent in the Nasiriyeh area owing to the elaborate bathing arrangements prepared for the troops, and no case of lice-borne disease was reported, although 945 cases of typical sore are known to have occurred in this area.

The bed-bug was not seen either in the divisional area around Nasiriyeh or in the city, although extensive searches were made for it.

All attempts to transmit infection by *Stegomyia fasciata* failed. In Nasiriyeh and Amara there were very few mosquitoes, and the incidence of malaria was low.

In India, Mackie found that 10 per cent. of the female *Phlebotomus minutus* were found to be infected with a flagellate of the genus *Herpetomonas*.* Acton carried out in Amara a series of experiments which demonstrated the close similarity between the distribution of sandfly bites on the human body and the distribution of the 517 cases of oriental sore examined by him. From a summary of the whole evidence he believed that the transmitting agent must be a blood-sucking dipteron which has a small or not very penetrating proboscis, and so can only attack thin, hairless areas of skin unprotected by clothes. The insect attacks the arm and leg during the day and the face and hands during the night. He came to the conclusion that the sandfly was the most likely agent concerned with the disease in Mesopotamia. Naidu believed that the *Phlebotomus minutus* was the transmitter of the disease in Nasiriyeh, as *Phlebotomus*

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* Wenyon was the first to demonstrate this fact during work at Aleppo.

papatasii and sandfly fever were prevalent during the period May to October, while *Phletobomus minutus* and oriental sore were in evidence from November to March. The *Phlebotomus minutus* has been found to breed under palm-leaf mud, in earth under flower-pots that had not been moved for three months, in heaps of garden refuse left untouched under a tree for a year, in shady corners of public gardens, in old undisturbed rubbish heaps, in damp corners of cellars full of old furniture and domestic dejecta, and in damp earth from the floors of unused houses full of brick debris.

The exact period of incubation of the disease was difficult to define, but observers reported a certain number of sores occurring within 3, 7, 15 and 30 days from the date of a known trauma.

Clinical Varieties.

An official circular issued in 1917 described four types of sore occurring in Mesopotamia: a papule, a tumour covered by glossy unbroken skin, a flat ulcer and a deep ulcer with heaped-up edges. Individual observers used their own terminology to describe the changes brought about by the stages of the disease, the amount of tissue reaction, the occurrence of ulceration and secondary infection. Cope recognized the following clinical types: the papule, the rounded ulcer, the psoriasis-form, the lupoid, the syphiloid and the epithelioma-like.

The appearance of the sore was heralded by irritation of the skin at the site of the scratch or insect bite. After a few days the affected area became raised and formed a small papule $\frac{1}{8}$ to $\frac{1}{4}$ in. in diameter. This papule became reddened, and was surrounded by an areola of subacutely inflamed cuticle. No constitutional disturbances were observed. The papule usually grew in size, and the epithelium covering it became shiny and whitish in hue. The sores either resolved or extended with or without ulceration.

In the non-ulcerating type a deep fissure sometimes formed on the surface and later in the depth of the tumour. These fissures occasionally multiplied, and the sore developed the appearance of a fungating or cauliflower-like growth, which usually ulcerated and became infected by pyogenic organisms. Occasionally the sores broke down after healing had commenced, and in some cases secondary groups of papules developed round the primary lesions. The sores did not invade the underlying tissue to any great depth, but they might extend and involve an area of skin varying from $\frac{1}{4}$ to 3 in. in diameter.

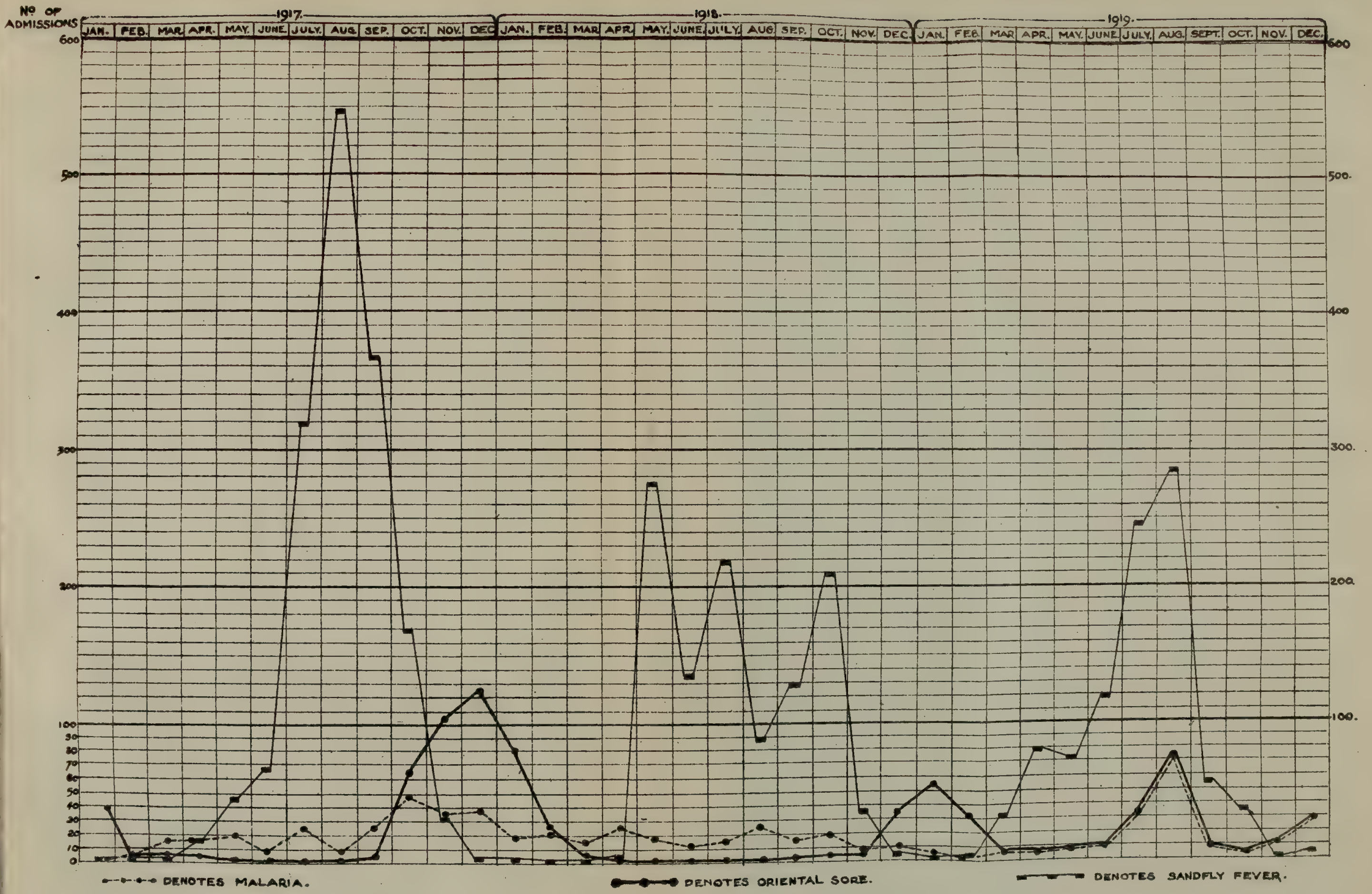

CHART VII.

SHOWING THE INCIDENCE OF ORIENTAL SORE COMPARED WITH THAT OF MALARIA AND SANDFLY FEVER.

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Malby & Sons, Lith.

The ulcerated sores exuded a serous fluid which became inspissated and formed a dirty yellowish-brown scab over the ulcer. The neighbouring glands were not enlarged, but ulcers situated near the eyes or mouth frequently caused œdema of the eyelids and mucous membrane of the lips and might imitate malignant ulcers. The sores if left untreated might persist for two years. No age was immune, but one attack appeared to confer immunity.

With regard to the pathology of oriental sore, the macroscopic and microscopic pathological features of the sores were well known before the war, and no further important feature was discovered during the war.

The *Leishmania tropica* was found throughout the structure of the non-ulcerated forms, and in the growing edge of the ulcerated types. It was found in 30 per cent. of all sores examined in Mesopotamia. It is known that the Leishman-Donovan bodies in kala-azar and oriental sore are indistinguishable, and also that the flagellate forms obtained by cultural methods are practically identical in the two diseases, but the exact relation between kala-azar and dermal Leishmaniasis is still undecided. It is interesting to note that indigenous cases of kala-azar have been reported from Mesopotamia.

Diagnosis.

It is important to note that, unless dermal Leishmaniasis is suspected, the sores may not be diagnosed correctly, as they may resemble lupus, syphilis, psoriasis, malignant disease, or a lesion due to staphylococcic infection. The differentiation can only be made with certainty by microscopic or cultural examination.

In obtaining specimens for microscopical diagnosis a satisfactory technique is essential. The details vary according to the sore under consideration. For open sores Acton advises the following method. The ulcer should first be cleaned by boric fomentations and the surface wiped with cotton-wool to remove any pus. With a sterile knife the ulcer should be scraped gently and lightly so as not to make the granulations bleed. The granulation tissue at the extending margin under the surface epithelium is the best site to find the *Leishmania tropica*. The scraped-off tissue at the edge of the knife is spread carefully on to a slide ; if too much pressure is used the endothelial cells burst in the process of spreading and the

Leishmania are made extra-cellular and scattered over the slide. The slide is fixed in the usual way and stained with Giemsa.

The parasite must be seen to contain a round tropho-nucleus and a bar-shaped kineto-nucleus, often showing merely as a dot, before it can be diagnosed. Blood platelets and cell inclusions may simulate the parasites.

For non-ulcerating varieties Shortt recommends that an ordinary capillary pipette with one end re-drawn to a finer bore be provided with a rubber teat and used in the following manner : The teat of the pipette is compressed and the point is pushed well into the substance of the sore, turned about and allowed to remain for a few seconds. Compression is relaxed and the pipette withdrawn. If the procedure has been successful a little serum or blood containing tissue cells has been drawn up and this should at once be expressed on to a slide and smeared on it with the end of the pipette or a needle.

Treatment.

Almost every remedy which has ever been suggested for skin lesions has been tried. When Evatt described the sores in 1874, carbolic acid and glycerine were said to be effective. The inhabitants of Bushire believed in tincture of iodine. Carbolic acid, silver nitrate, potassium permanganate, methylene blue, β-naphthol, boric acid, balsam of Peru, ichthyol and iodoform have all had their advocates. Broome obtained good results with carbon dioxide snow, Mitchell with carbon dioxide and curetting, Splendore with radium treatment, Paterson with Finsen light, Hergscheimer and Borgen with X-rays, and Row with a vaccine prepared from cultures of *Leishmania tropica.* Schlugin treated 300 cases by freezing with ether, and Gueyat obtained a cure in three to eight weeks by using an ointment of salicylate of bismuth and methyl salicylate.

In one division each medical unit was advised to try only one method of treatment, as it was advisable to obtain, if possible, some definite guide for the therapy of sores in the field. One unit tried exposing the sores daily to the sun for a few hours, and the application of a soothing ointment. Some units tried the application of tincture of iodine ; others cauterized the sores with carbolic or nitric acid, and then applied moist antiseptic dressings.

In No. 105 Combined Field Ambulance the sores were dusted with calomel, and after twenty-four to forty-eight hours dressed with black wash followed by blue ointment when healing commenced. When healthy granulations appeared, and the marginal epithelium began to grow in, the sore was covered with a clean polished lead plate. The plate was sterilized and changed daily, and served as a mechanical protection to the ingrowing epithelium. This treatment was tried in 341 cases. Sixty-five per cent. were successfully treated and cured in a month. The patients suffered no discomfort. The materials were easily obtained, and produced no symptoms of toxic poisoning.

The other methods tried in Mesopotamia were local applications, exposure to X-rays, ionization, and the operative methods of excision, curettage and intravenous injections.

A 1 per cent. or 2 per cent. aqueous solution of methylene blue was used as a moist dressing, and an ointment of equal parts of methylene blue, vaseline and lanoline was tried. The patients complained bitterly of the pain and discomfort of both forms of treatment. The time taken to effect a cure varied from 28 to 109 days.

A 2 per cent. aqueous solution and a 2 per cent. ointment of antimony tartrate were used. The sores usually received a preliminary cleansing with boric or eusol fomentations. Fifty-seven cases were treated, and 59 per cent. were cured in thirty days. The treatment was best suited for clean ulcers. It occasionally caused œdema of the surrounding skin.

A 2 per cent. aqueous solution of zinc sulphate or zinc ointment was used. Eighty-one cases were treated, and 35 per cent. were cured in thirty days. Fifty per cent. showed no improvement, but a pronounced bacterial infection.

Evans obtained good results by using powdered corrosive sublimate.

The application of tincture of iodine was tried and found as unsatisfactory as in 1839. Eusol was found to have no action on the *Leishmania tropica*. It was subsequently used in the preliminary cleansing of an infected sore.

With regard to X-rays, Naidu tried a dose of 10 milliamps. given at a distance of 12 in. through a 0·5 mm. aluminium filter in sixteen cases. The number of exposures varied from one to forty-two, and he gave up the method, as in his hands it proved unsuccessful, and resulted frequently in dermatitis.

Ormerod found that the high temperature in such a climate as Mesopotamia caused difficulties and deterioration of X-ray tubes working for any length of time. As the tube heated up the vacuum decreased, and softer radiations, less useful therapeutically, and more dangerous to the patient, were emitted. To minimize this, an electric fan was kept playing on the tube whilst it was working. The dose of X-ray administered was estimated by exposing at the time of the application a Sabouraud pastille coated with barium platinocyanide and noting the time taken to produce the standard orange tint. The average time taken was twelve minutes.

The time taken by the ulcer to heal varied according to its age and sepsis. Shallow, comparatively clean ulcers were healed in ten days, whilst some of the chronic, heavily infected ulcers took two months.

Ormerod states that the average time to effect a cure by treatment with X-rays for one hundred ulcers of every age and degree of sepsis was twenty-seven days. It was noted that the scars left after treatment were soft, pliable, and pink in colour, and became almost unnoticeable after six months. In thicker skins, and after much suppuration, the scars might be discoloured by brown pigment. In a certain number of cases the treatment was unsuccessful.

Early in 1918, Major A. C. Norman, supervising X-ray specialist with the Mesopotamia Expeditionary Force, became interested in the treatment of sores by X-ray. In summarizing the results of X-ray treatment he states that the acute type of oriental sore heals more rapidly than the indolent type. The indolent type is subject to periods of exacerbation, during which it is particularly amenable to X-ray treatment. These periods are denoted by increased redness and swelling, and may be artificially produced by the application of a 2 per cent. ointment of tartrate of antimony. Sores situated over cartilages and bony prominences are more resistant to treatment than when situated over soft parts. The unsatisfactory results so frequently reported after X-ray treatment were, he considered, due to insufficient dosage at the outset. Experience suggested that an initial dose of X-rays which was too small to kill off the Leishman bodies rendered them more resistant to X-rays, so that subsequent treatment became very difficult. He advised the first application to be at least a full pastille dose, filtered through no more than 0·5 mm. of aluminium. If necessary, this should be followed at an interval of one week by a second pastille dose given through a thicker filter.

Doyle exposed a sheet of lead-foil, 6 in. square, to X-rays at a distance of 6 in. from, preferably, a soft tube for fifteen minutes. Appropriate pieces were cut from the lead-foil and applied to the sore; they were held in position by a bandage. The lead-foil was changed every four days. He treated twelve chronic cases in this manner and all were cured in three weeks.

As mercurial preparations had proved efficient in the treatment of ulcerating sores, ionization with perchloride of mercury was tried in 169 cases. A single application frequently aborted the papular stage of the disease, and in non-ulcerating conditions it usually effected a rapid cure. This was specially noticeable when such sores were situated on the face. In cases with multiple sores the treatment was long and tedious.

A similar number of cases was treated by ionization with a 2 per cent. solution of antimony tartrate. It acted more quickly and efficiently than perchloride of mercury.

Only a few cases were treated by ionization with a 2 per cent. aqueous solution of zinc sulphate, and the results were not so satisfactory as those obtained with mercury and antimony.

Harries obtained good results by excising the sore, but other officers who tried this method of treatment gave it up.

Curettage required an anæsthetic, but effected a cure within thirty days in the majority of cases.

Although Patton and Newman had found the *Leishmania tropica* in the peripheral blood stream, some medical officers did not favour the treatment of dermal Leishmaniasis by intravenous injections of tartar emetic. The method was extensively tried in Mesopotamia and intravenous sterilized injections of a 1 per cent. solution of tartar emetic were given in doses varying from 5 to 7·5 c.c. of the solution. Cases suffering from multiple sores were usually cured in a month. Occasionally the injections were followed by local symptoms at the site of the injection and by general symptoms, injection of the conjunctivæ, increased lachrymation and respiration, cough, and vomiting. Sometimes a cure was effected by one injection, but in the majority of cases the injections were repeated at intervals of four to seven days in the absence of general symptoms. They were discontinued when healing of the sores commenced. The intravenous method of treatment required a certain amount of experience and was more suitable for a stationary or general hospital than for general use in all medical units.

Early in 1918 experiments were tried to produce a curative vaccine for oriental sore, but this treatment was not developed.

The treatment of oriental sore by injecting emetine has been recently recommended.

The methods recommended for preventive measures and prophylaxis are the use of nets with close meshes (22 holes to the linear inch) during the night, the use of a repellent, such as vermijelli, and the covering of every cutaneous lesion with a protective dressing in order to prevent flies settling on it.

TROPICAL SKIN DISEASES.

In the military operations conducted in tropical and subtropical countries, various skin affections assumed importance, as a cause both of temporary inefficiency and often of invaliding. For example, in East Africa, the frequency of infestations by *Dermatophilus penetrans* (chigger flea) was a potent source of sore feet among European and Indian troops, while *Ulcus tropicum* among the natives in the Carrier Corps was also responsible for much invaliding and permanent deformity. Other pathological skin lesions, such as veld sores, were a sure indication of debility and a warning to the medical officer that the health of the troops in his care was becoming undermined.

A brief description of the more common of these cutaneous affections is therefore of interest.

Veld Sore.

The fact that to this type of ulceration many local terms such as barcoo rot, desert sore, septic sore, fever sore and Gallipoli sore are given, indicates its widespread occurrence. The usual sequence in the development of the lesion was the occurrence over some small abrasion, such as a graze or mosquito bite, of a small vesicle surrounded by a zone of hyperæmia and containing serous fluid. On rupture of the vesicle a shallow ulcer was left, often with a markedly tender surface. This superficial ulcer extended slowly at the margins, but not as a rule to any depth, eventually reaching a chronic stage, when it appeared as a somewhat punched out ulcer with thickened and undermined edges. The floor of the ulcer varied in character, and in those cases due to infection with the Klebs Loeffler bacillus was covered with a greyish adherent membrane, which was removed with difficulty leaving a raw and bleeding surface. As a rule exposed parts and those portions covered with hairs, for example the dorsum of the hand, the extensor surface of the forearms, the inner side of the knee and the skin above the ankles, were particularly attacked, but any portion of the body might be affected.

Some observers maintained that these ulcers also occurred on healthy skin. In most cases veld sore attacked troops debilitated by various causes, such as the intensely hot and dry climate of desert areas, or the high temperature combined with excessive humidity of low-lying parts of East Africa during the rainy season. Deficiency in rations, both quality and quantity, neglect to keep the skin clean or to dress minor abrasions, chronic malaria, and other debilitating diseases can also be cited as contributory factors of this condition.

The micro-organism present in the majority of cases was the *Staphylococcus epidermidis albus*, which, owing to the lack of resistance of its host and the unhealthy condition of the skin, was enabled to take on invasive properties.

Other organisms, *S. aureus*, *S. citreus* and occasionally diphtheroids, were isolated from these lesions, and in a few cases, streptococci also were recovered from the fluid of unbroken vesicles.

Progress and Treatment.—These ulcers were very intractable to treatment if, from military exigency, patients were compelled to remain under unsatisfactory conditions. As a rule, simple wet mild antiseptic dressings were better than dry dressings. In East Africa it was a common experience to find that ulcers which had completely resisted treatment during the rains and were almost accepted as intractable to treatment, healed in a few days on the onset of dry weather, no further treatment than the simple wet dressing being necessary to ensure complete healing. Similarly on change to different surroundings, such as a hospital ship or to higher altitude, the ulcers rapidly healed, leaving a pigmented glossy scar free from hair and sweat glands.

Lieut.-Colonel C. J. Martin found in cases among troops operating east of the Suez Canal that infection of the hair follicles is one of the main causes of retarded healing, and possibly also the original site of implantation of the infection. He also showed that if the hairs were epilated from unbroken vesicles, healing often took place without ulceration, and that in the more advanced cases epilation of the hairs on the surface and at the margin of the ulcer caused prompt improvement.

Diphtheritic Infection of the Skin.

On various occasions in the Mediterranean area, virulent Klebs Loeffler bacilli were isolated from sores.

In the Sinai Peninsula, Dr. Craig found that 67·5 per cent. of his cases of superficial ulcerations were so affected. At the time these cases occurred, diphtheria, both faucial and nasal, was prevalent among troops. Infection was either implanted on an abraded surface directly or occurred as a secondary infection in veld sore. Such cases were occasionally associated with weakening of the affected limbs and, later, paralysis.

Treatment.—The administration of 4,000 units of anti-diphtheritic serum injected subcutaneously in the vicinity of the sores promoted rapid healing and disappearance of the ulcers.

Ulcus Tropicum (*Tropical Sloughing Phagædena*).

This formidable type of ulceration occurred mainly among natives in the Carrier Corps in East Africa and was responsible for many patients being invalided. Those commonly attacked were debilitated, but the condition was by no means rare in healthy and vigorous individuals.

The specific organism of this lesion has not yet been satisfactorily identified, and many of the effects must be due to a secondary infection. The *Bacillus fusiformis* and spirillum of Schaudinn were present in a large number of cases. Commencing in the same manner as in veld sore, the ulceration, however, extended more rapidly, and this extension was widespread.

The surface of the ulcer became covered with a slough which in a few days liquified in the centre, while ulceration proceeded at the margins. In more severe cases deeper structures, such as muscles, tendons and bones became involved, and great deformity ensued on repair of the lesion. When the slough was finally cast off the extent of tissue destruction was the most striking feature.

General symptoms, though occasionally severe, were usually surprisingly mild.

Treatment.—Various methods of treatment were employed and extolled :—

(*a*) The sore was painted with formalin, applied to the surface on a cotton-wool tampon once a day for two to three days. Directly a scab had formed it was covered with a bismuth paste dressing.

(*b*) Normal saline was introduced deeply under the floor of the ulcer, and the surface covered with gauze dressing saturated with normal saline.

(*c*) A sodium chloride solution—sodium citrate 1·5 per cent. in 20 per cent.—was applied as a wet dressing. It prevented the clotting of lymph and stimulated the flow of lymph by osmosis.

(*d*) The most common form of treatment used in East Africa was that recommended by Manson. Pure carbolic was applied freely to the surface of the ulcer, the limb was then elevated and the surface of the ulcer was irrigated with some weak antiseptic. The ulcer was covered with skin-grafts when the granulation tissue became healthy.

(*e*) Instead of digesting the slough with pure carbolic the ulcer was occasionally curetted, and this form of treatment acted well in many cases.

(*f*) Injections of salvarsan were tried by some observers, who noted good results.

Furunculosis.

Boils were common in all areas, but in Egypt and the Sudan a particular type of septic furuncle was prevalent. This was named the " Nile boil."

The particular characteristics of this lesion were the early slough formation, the well-defined zone of hyperæmia and the marked œdema and infiltration of the surrounding tissues. The slough broke down slowly and, when exfoliated, left a deep-seated ulcer which healed from the bottom and caused much scarring.

Staphylococcus epidermidis albus was the responsible organism in many cases, but a variety of *Staphylococcus aureus* was also isolated.

Treatment.—The treatment was mainly expectant, until the central slough had liquefied and was ready for extrusion, when free incisions were made into the boil. This local treatment was often favourably influenced by injecting the patient with a vaccine prepared from strains of the causative organism.

Pemphigus Contagiosus.

A small outbreak of *Pemphigus contagiosus*, also due to a variety of staphylococcus—*Staphylococcus pyogenes aureus*—occurred among troops in Khartoum. In this condition large vesicles or bullæ appeared on apparently healthy skin. They became turbid and finally ruptured, after which healing took place without ulceration, inflammation around the bullæ being conspicuous by its absence.

Treatment. — The affection was highly contagious, but responded promptly to the application of some mild antiseptic lotion or a dusting powder composed of equal parts of boric acid, starch and zinc acid.

Dhobie Itch (Tinea Cruris).

The term dhobie itch included infection caused by various types of fungi, for example, the trichophytons of ordinary body ringworm, *Microsporum furfur* and *Microsporon minutissimum.* The disease occurred in all hospital areas. Certain individuals suffered intensely during the hot weather from the excessive irritation caused by this disease. The irritation was relieved by scratching which led to septic infection and lack of sleep. Unless the condition was cured the sufferer was admitted to hospital.

The dermatitis and irritation subsided spontaneously without treatment on the approach of the colder weather, but a scurfy pigmented surface remained and on the return of the hot weather the irritation usually became active again.

Treatment.—The application of chrysophanic acid ointment, 20 gr. to the ounce of vaseline, was uniformly successful. The ointment was rubbed in twice a day until erythema was apparent at the advancing edge. Resorcin and salicylic acid in ointment form were useful. Equal parts of the liniment and the tincture of iodine were also applied with success, but this application caused intense smarting and irritation, factors which militated severely against its general use.

In connection with the prevention of this disease it has been pointed out that if possible the underclothing or clothing in contact with the infected surface of skin should be ironed daily with a hot iron to prevent re-infection.

Trichonocardiasis.

Trichonocardiasis was met with in East and West Africa. It mainly affected the axillæ, causing irritation of the skin of the affected part and staining of the clothes. The parasite was the *Nocardia tenuis,* either occurring alone or in combination with chromogenic diplococci, giving rise to a variety of colours apparently depending on the variety of diplococcus present. In East Africa the variety causing the brick-red colour, *T. rubra,* was usually present, while on the west coast the yellow variety, *T. fusca,* predominated. The shafts of the hairs had a beaded or nodular appearance. The nodules were easily scraped off the surface of the hairs and under the microscope were found to consist of narrow elongated unbranched non-septate rods.

MacFie obtained cultures from scrapings of nodules soaked in absolute alcohol and planted in ascitic agar.

Treatment.—A spirit lotion consisting of formalin 1 drm. to 6 oz. rectified spirit, was applied twice a day, in addition to the application of a 2 per cent. sulphur ointment.

Ulceration caused by Dermatophilus penetrans.

Dermatophilus penetrans, or chigger flea, is widespread over tropical Africa, is particularly prevalent on the east coast, and in many areas in the more central part of German East Africa. The male and female fleas are free-living. The latter, when impregnated, burrows under the skin of any warm-blooded animal, dogs in particular being affected, and proceeds to ovulation. Its abdomen eventually reaches the size of a small pea.

Severe irritation leading to the formation of pus is caused in the tissue around the insect. Finally the superjacent skin ulcerates and the flea is expelled. Any portion of the body may be affected, but as would be expected, the feet are the usual site, more particularly the roots of the toe-nails, the skin between the toes and the soles of the feet.

Prophylaxis.—A daily foot inspection of all troops by some competent person, preferably an intelligent native, is a necessity in a chigger-infected area. Individuals vary greatly as regards sensitivity. In some, great irritation is caused by the actual boring process of the insect, and this leads to a prompt examination of the feet and early removal of the cause. In others, although 40 to 50 chiggers may be present, the patient is unaware of their existence until pus formation and ulceration occur. Therefore whether irritation is felt or not the feet should be examined minutely and completely once or preferably twice a day.

Floors of rooms, huts and tents must be frequently swept, the dust removed and the floors kept moist with cresol solution.

Bare feet should be well rubbed daily with an ointment consisting of lysol 15 minims and vaseline 1 oz. They should never be put on the ground. Socks and boots should be damped with kerosene and placed at a height above the ground. High boots, such as mosquito boots, should always be worn. In Korogwe, in German East Africa, the measures adopted were never a complete protection, and the daily extraction of the insects became a necessary routine.

Treatment.—A small orifice in the skin over the chigger is enlarged with a clean needle and the flea enucleated entire. Europeans may in time become expert at performing this little operation, but a native as a rule performs it more satisfactorily and very skilfully. In the early stages, removal of the flea with subsequent application of iodine to the affected spot is all that is required. If the condition is allowed to suppurate, it must be treated surgically, as the nails involved have often to be removed before healing will take place.

Boils caused by the Larva of Cordylobia anthropophaga.

Another skin infection met with in East Africa was that caused by the larva of *Cordylobia anthropophaga*, known on the west coast as the Tumbu fly. Apparently the infection is caused in man by the fly laying its eggs on dry ground or on exposed clothing. The larva burrows into the skin of man or animals and causes a small inflamed swelling, usually considered to be the commencement of an ordinary boil. Any portion of the body may be attacked but as a rule the lesions are confined to those parts of the body covered by clothes. The small opening at the apex of the swelling is usually evident, and by applying slight pressure, the larva is extruded.

Treatment.—Chloroform should be painted over the affected part before pressure is applied to the boil as this sometimes assists the extrusion of the larva. Iodine and simple dressings lead to prompt recovery.

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CHAPTER III.

VENEREAL DISEASES.

IT has not been possible to obtain exact figures showing the prevalence of venereal diseases amongst the British forces during the war, and the following must be regarded only as approximate, subject to correction and amplification when the full records have been analysed. With this reservation the number of cases of venereal disease treated in the period 4th August, 1914, to 11th November, 1918 was about 400,000, distributed very approximately as follows :—

Gonorrhœa	66 per cent.
Syphilis	24 ,,
Chancroid	6 ,,
Other venereal diseases	4 ,,

The ratios of admission per 1,000 per annum of all troops, British and Dominion, for the different years and in the different theatres of war, were approximately as shown in the table below. Where spaces are unfilled no figures are available :—

	In U.K.	France.	Italy.	Egypt.	Salonika.
1914	51·8	—	—	93·7	—
1915	—	30·5	—	—	—
1916	36·7	23·7	—	64·3	—
1917	37·8	—	—	28·2	—
1918	43·0	32·0	41·2	51·8	12·0

The ratios of admissions per 1,000 per annum of certain Dominion forces were supplied to the Interdepartmental Committee on prophylaxis against venereal disease as follows :—

	Canadian.	Australian.	
	U.K. only.	U.K.	France.
1915	222·0	—	—
1916	209·4	—	—
1917	114·0	(2nd half) 168·8*	85·0
1918	81·6	148·0*	64·2

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* To these rates must be added 78·4 for 1917 and 101·1 for 1918, on account of cases of gonorrhœa treated successfully by the abortive method and not admitted to hospital.

The rates for the whole British army, including Dominion forces, compared favourably with the rates for the three previous peace years, 1911 to 1913, as shown in the following table :—

	United Kingdom.	Abroad.
1911	60·5	68·7
1912	56·4	69·9
1913	50·9	68·1

It will be seen from the tables that the incidence of venereal disease differed in the various countries and forces engaged. The variety of factors involved makes it impossible to venture more than a surmise as to the probable causes of these differences, but it is reasonable to suppose that it was closely connected with the proximity of troops and opportunities of access to large centres of population. A considerably larger proportion of the troops in the United Kingdom than in France was stationed close to large towns, and their opportunities for venereal exposure were consequently greater. Analysis of the tables indicating places of infection in France showed clearly that the closer troops were to a large centre of population the higher was the venereal rate. Out of a random sample of 14,433 cases admitted to hospital in France, 3,741 were found to have been infected in Great Britain, and of 5,987 stated to have been infected in France 3,202 were found to have been infected as follows :—

Place.	Total.	Percentage of Total Weekly Average.
Rouen	1,617	11·2
Havre	680	4·7
Boulogne	357	2·4
Calais	139	0·95
Dieppe	140	0·95
Marseilles	269	1·8

What proportion of the venereal rate in France and Italy was attributable to infection in the United Kingdom and *vice versâ* is uncertain, but the above analysis appears to indicate that those infected in the United Kingdom formed a substantial percentage of those admitted in France. No similar statistics are available as to infection imported into the United Kingdom, but many factors operated against such an importation, notably the rule in France making a soldier ineligible for leave for twelve months after contracting venereal disease, also the fact that the majority were infected whilst on leave, and that most leave was spent in the United Kingdom. Therefore, although accurate statistics are not available, it is reasonable to suppose that more venereal disease was imported into France from the United Kingdom than *vice versâ*. It cannot be inferred from this that venereal disease was more prevalent amongst the civil population of the United Kingdom than in that of France. When soldiers were allowed to spend their leave in Paris the number of infections contracted in that city became very considerable.

It is difficult to account completely for the difference between the British rates and those of the Dominion forces, but probably few will deny that access to large towns and abnormal surroundings accounted largely for the higher rates amongst the latter. The average British soldier proceeded to his home in some village or small country town ; the average soldier of the Dominion forces found his way to London. The former found abundant distraction in many home interests, the latter had perforce to seek more artificial amusements. The first operated against sexual incontinence, the latter favoured it. It is quite possible that the proportion of individuals exposed to infection was similar in both forces, but, on account of the influences mentioned, the number of exposures per individual was considerably less in the case of the British soldier than of his comrade from the Dominions. Colonel Ashburn's investigations in the American army and Colonel Harrison's in the British indicate that to males the all-round risk of infection from illicit sexual intercourse without precautions is about 3 per cent., so that the number of exposures per individual operates very strongly on the venereal rate.

It cannot be said that the reason for the difference between the British rates and those of the Dominion forces is to be found in the medical methods of prophylaxis adopted, because, as will be seen, the prophylactic measures of the latter were much more thorough than those of the British.

Measures of Prevention.

The British Expeditionary Force went to France provided with a leaflet by Lord Kitchener exhorting the troops to continence.

The National Council for Combating Venereal Disease worked hard in the prevention of venereal disease and it obtained the permission of the War Office to deliver lectures to the troops on the evil results of venereal disease. Altogether 1,956 lectures were delivered by carefully selected lecturers during the war to a total of 1,621,943 troops in the United Kingdom. Similarly it arranged 580 lectures to munition workers, male and female. It issued pamphlets specially addressed to soldiers and munition workers under the following titles: "Prevention of Venereal Disease in the Army," and "A Lecture to Troops," by Dr. Otto May. Others were "Beware" and a pamphlet for women workers entitled "England's Girls and England's Future," as well as a special pamphlet for members of the women's services, prepared by the medical departments of the services in co-operation with the National Council. The Council also interested itself in reducing the plague of loose women around camps, at railway stations and on the streets, and in securing the special instruction in venereal diseases of temporary officers on joining the R.A.M.C. It is impossible to estimate the effect of these efforts of the N.C.C.V.D. on the venereal rate since nobody can say what it would have been without them. It is, however, fair to say that they commenced long before any measure of prophylaxis by disinfection was adopted by the British troops, and that the rate in the British army was lower in the United Kingdom than any prior to the war in spite of the admittedly greater temptations to sexual incontinence which prevailed. In this connection it is safe to say that social conditions operated strongly during the war in favour of a high venereal rate. The sexual morality of females was definitely lower than in peace. The excitement of war, the halo of romance surrounding the soldier, and the greater freedom of life which women enjoyed as a natural consequence of their undertaking, during the war, work which in peace time is performed by men, tended temporarily to lower the normal moral code of women. Support for this statement is found in the behaviour of women and girls in the streets of large towns, and in the fact that amongst the British troops a careful enquiry in some thousands of cases showed that over 60 per cent. of the infections resulted from intercourse with women who were not prostitutes in the ordinary sense of the word, since they received no payment. In the Australian army about 60 per cent. of infections were due to professional prostitutes, probably because of the higher pay of the soldiers.

Lieut.-Colonel Sir J. W. Barrett, of the Australian A.M.C., reported on the system of prophylaxis he established in Egypt during the war. The measures, in which he was assisted energetically by the Cairo Purification Society and, on the moral side, by the Y.M.C.A., consisted in :—

" (1) Rigorous repression of public indecency, unnatural offences, the suppression of pimps, the control of advertisements and the restriction of the sale of alcohol.

" (2) Continuance of the system of medical examination of prostitutes.

" (3) Provision of ablution rooms and the supply of prophylactics.

" (4) Moral and hygienic lectures, guides to meet trains, and the like."

The venereal disease rate appears to have ebbed and flowed with the energy with which these measures were enforced, the author remarking on three periods when energetic efforts resulted in the disease being brought under control.

Colonel Elgood, at Port Said, coped with the problem at first by :—

" Suppression of the white slave traffic."

" Closing of brothels in the European quarter."

" Segregation of the women, who would not leave Port Said, in the Arab quarter, where they were placed under the control of the medical officers of the Egyptian Public Health Department, and were subsequently examined."

Experience proved that the results of such medical examinations are misleading and dangerous, and a sub-committee of the Cairo Purification Society was formed at Port Said to deal with the local aspect of the problem and to assist in the development of healthy social agencies for the benefit of the men. The following measures were also employed :—

" The punishment of pimps and touts."

" The restriction of the sale of alcohol to the hours of 1 to 3 p.m. and 6 to 9 p.m. Enforcement of this order was difficult."

These measures failed to effect any improvement, and the ablution tent was established. This appears to have been a system of disinfection by, or under the supervision of, trained attendants, as distinct from self-disinfection. The result is stated to be that of 9,282 men who passed through the local rest camp 4,580 reported exposure, and there were only 13 infections. It is not stated how long the men remained in the rest camp and what steps were taken to follow their history afterwards.

In the Canadian Army soldiers were lectured to by medical officers on arrival, every six weeks thereafter in the lines, and every week in the convalescent depôts.

A similar system of lectures prevailed in the Australian and New Zealand Forces.

In 1918 a specimen lecture was issued by the War Office, chiefly directed to the risks of incontinence and the importance of very early disinfection after exposure.

The measures of a penal nature adopted by the different forces, composing the British Army, varied considerably. The policy in the Imperial Army was to avoid punishment except for concealment of disease, since long experience had shown that punitive measures increase concealment. It is true that the officer or soldier who contracted venereal disease had to pay hospital stoppages (2*s*. 6*d*. per day in the case of officers and 7*d*. in the case of men), but these are payable under the allowance regulations in all cases of sickness requiring hospital treatment, except in cases where the sickness is attributable to service in the field. During the war all sickness, except venereal disease and alcoholism, was admitted as contracted through service, so that venereal disease differed only in the fact of losing a privilege accorded to other diseases during the war.

Proficiency pay was also lost, usually at the discretion of commanding officers, as in peace. Officers and warrant officers forfeited field allowance during their stay in hospital for venereal disease as if they were on leave.

In the Canadian, Australian and New Zealand forces fines were imposed for the contraction of venereal disease.

A temporary officer of the Imperial Army who was in hospital for more than four months for venereal or other disease not attributable to service was reported to the Army Council for the question of his retention in the service to be considered.

In France, by an order dated 27th January, 1917, an officer or soldier who contracted venereal disease was not eligible for leave for twelve months from the date of leaving hospital. In theory such an order might be salutary in two senses—first, as a deterrent, and secondly, as a means of preventing disease being carried to families. In practice it is possible that it became largely inoperative, since a soldier was likely to be evacuated to England for other disease or for wounds long before the year was over.

Segregation and Treatment of Prostitutes.—In the forces overseas a system of identification was established by which infected soldiers were afforded opportunities of identifying women who had infected them. These were taken to hospital, medically examined, and, if found to be diseased, were removed from the locality. This system commenced in No. 9 Stationary Hospital, Havre, early in 1915, when an officer was detailed to interview all newly admitted patients and extract from them as much evidence as possible which would lead to identification of the source of infection. If the latter was in Havre the soldier was taken to the house. If at another station, careful directions for identification were despatched to the headquarters of the formation concerned each week and acted upon by the Assistant Provost Marshal subsequently. As far as possible soldiers were detained in field ambulances or casualty clearing stations until they had an opportunity of personally identifying the source of infection. In very many cases women so identified were declared by the examining doctor to be free from disease, but the examination usually conducted was such as is likely to detect only the grosser signs. On the other hand, many diseased women were removed from the vicinity of the army as a result of these identifications.

Segregation and Treatment of Infected Soldiers.—The thorough treatment of infected officers and soldiers in hospital must be reckoned as a measure of prevention. There is much to be said against hospitalisation of soldiers suffering from venereal disease, with all its evils of enforced idleness and the wastage of man-power which result, but in times of war soldiers live in such close contiguity and under conditions so adverse to personal cleanliness that the risk of cross-contagion demands segregation during at least the acute stages. Further, to allow soldiers suffering from venereal disease complete freedom must lead to more widespread infection of women, and so to the increase of venereal disease in the army. The low incidence during the war of extra-genital chancre, by no means always non-venereal, which Major C. F. White and Captain W. Brown found in an analysis of 9,000 cases of syphilis to be 0·9 per cent., and the comparative rarity of gonorrhœal ophthalmia, which occurred in less than 1 per 1,000 cases, and then almost invariably by auto-infection, may be due in some degree to the policy of segregation of infected soldiers adopted by the British army.

Maisons de Tolérance.—In 1915 the Medical Officer of Health and police authorities in Havre represented that, if a certain street in Havre which had been put out of bounds were opened to troops, the prostitutes living in it would follow the advice of the British medical authorities in taking measures to prevent conveyance of infection. The street was put in bounds on these conditions and placed under supervision. Captain Deane's statistics showed that in fifty-seven weeks 171,000 men visited houses in this street and only 243 stated that they had been infected there with gonorrhœa or syphilis. The experience coincides with one of Harrison's during peace when venereal disease was abolished from a certain station by similar measures. In Italy a strong opinion in favour of *maisons de tolérance* was expressed by officers at Taranto. It was found that, when the town was put out of bounds, the venereal rate rose remarkably, owing to uncontrolled women infesting the neighbourhood of camps. In Rouen the locally contracted infections for four months before *maisons de tolérance* were put out of bounds were 670 and for four months after, with a smaller average strength, 834. *Maisons de tolérance* were recognized in other towns in France, but the exact measures undertaken there are not on record. In April 1918 *maisons de tolérance* were put out of bounds to all troops, in deference to strong public feeling in the United Kingdom.

Personal Disinfection.—Early in 1916, on the representation of the National Council for Combating Venereal Disease, each British unit was provided with a compartment where there was an irrigator with 1 : 3,000 potassium permanganate solution and calomel ointment, with which soldiers were strongly advised to disinfect themselves after exposure to infection. The use of these facilities varied greatly with different units, depending mainly on the energy and personality of the medical officer. On the whole they were believed not to be a great success, chiefly because of their location in urinals, the reluctance of men to be seen going to them, and possibly the length of time which elapsed between exposure and disinfection. In France a similar system was adopted, and at Taranto, Italy, the system was extended by the employment of trained orderlies to disinfect men on return to camp. In the case of the British West Indian Regiment, in which venereal disease was particularly rife, skilled disinfection on return to camp was made practically compulsory, and the venereal admissions from this unit are stated by Captain C. Doble, R.A.M.C., to have dropped from 80 a week to 4 a month.

In 1917, Lieut.-Colonel L. W. Harrison advised that, in place of disinfection being available only at these compartments, soldiers should be supplied with tubes of calomel cream, as was being done in other forces. Experiments at Rochester

Row had shown that calomel cream destroys the gonococcus in gonorrhœal pus. This plan was not adopted until 1918, when a new system came into operation as a result of claims made by Sir Archdall Reid that he had practically abolished venereal disease from a certain barracks in Portsmouth by giving to men a small quantity of permanganate of potassium solution with which to disinfect themselves at once.

It was decided to make available to every man on request a bottle of potassium permanganate lotion (1 : 1,000), a small piece of cotton-wool, and a collapsible tube of calomel cream. Previous experience had shown that much of the success of a policy of venereal prevention by self-disinfection depends on the energy with which it is pushed by medical officers, supported by commanding officers. Accordingly a letter was issued by the Army Council directing attention to the serious wastage resulting from venereal disease and to the new measures of prevention about to be adopted, and holding commanding officers personally responsible for seeing that everything possible was done to make them a success. The Director-General, A.M.S., sent for all D.Ds.M.S. in the United Kingdom and personally informed them that he should consider it a slur on the efficiency of a medical officer if the venereal rate in the unit under his medical charge was not kept at the lowest limit possible. A specimen lecture, founded on one furnished by Sir Archdall Reid, was issued for the guidance of medical officers in addressing troops. Medical inspectors were detailed to tour districts allotted to them to see that medical officers were following the instructions on the subject and generally by personal endeavour doing their utmost to make the new measures a success. It was not until about August 1918 that the system can be said to have become at all operative in the United Kingdom and about November 1918 in overseas stations, so that it was only after active operations had ceased that any opportunity of judging the effect of this new system occurred. After the adoption of the system of self-disinfection the venereal rate rose somewhat instead of declining. The reasons for this have, however, become highly controversial.

The Australian and New Zealand system of issuing outfits for self-disinfection commenced considerably earlier than the British. The Australian system was briefly as follows. Each detachment of troops was lectured on the dangers and prevention of venereal disease immediately on arrival in a new station. Lectures were also delivered by medical officers at regular intervals to troops in all stations. Each man going on leave was similarly lectured to and offered a small box containing three collapsible tubes of calomel with camphor and carbolic cream and a packet of potassium permanganate tablets, with directions for use enclosed.

The directions advised use of the calomel cream before and after exposure. A condom was also advised, and soldiers were informed that further outfits could be obtained on application at a " Blue Light " depôt.

In the Canadian forces a collapsible tube of calomel cream was issued to all who applied for it. Apparently in some stations, as in Paris, outfits were offered. Instruction in the use of these outfits was given verbally. From April 1917 to February 1919, 571,180 tubes were distributed in England to a strength varying from 180,000 to 275,000. At Pépinière barracks in Paris, where facilities for disinfection were provided by the Canadian authorities for men on leave, from November 1917 to March 1918, 53,441 tubes were issued to men of all British forces arriving on leave, the number of these being 22,588.

Disinfection by Skilled Attendants.—In addition to the above measures of prevention by self-disinfection, the Canadian, Australian and New Zealand forces set up stations at which soldiers could be disinfected by skilled attendants. A soldier on reporting at one of the Australian centres was treated as follows :—

(1) Washed with soap and water.
(2) Washed with 1:2,000 mercury perchloride.
(3) Meatus and first half-inch of urethra swabbed with argyrol or protosil.
(4) Urethra injected with 10 per cent. argyrol or protosil.
(5) Parts well rubbed with 30 per cent. calomel ointment.

One of these stations was established wherever any large number of troops resorted, and enormous numbers of soldiers passed through them. Thus, at the Pépinière barracks, 25,017 treatments were given from November 1917 to March 1918.

At the Australian centre in London the attendances for treatment, including skilled disinfection and abortive treatment of gonorrhœa, mentioned below, from August 1916 to February 1919 were 222,882, and the weekly average attendance at the eighteen Australian centres in England in the last six months of the war was 4,623.

Abortive Treatment of Gonorrhœa.—In addition to affording prophylaxis by skilled disinfection many of these stations undertook the abortive treatment of early gonorrhœa in suitable cases and in this way saved large numbers of soldiers from admission to hospital. Thus, out of 7,366 Australian soldiers who were treated by the abortive method in the year ending 31st December, 1918, 5,350 were cured without admission to hospital.

A similar centre for British troops was established in 1918 at the military hospital, Rochester Row. Abortive treatment proved most successful in those cases where the discharge had not yet become purulent, but often succeeded also in those which had advanced slightly beyond this stage. Lieut.-Colonel G. Raffan obtained 96 per cent. of cures in those reporting within eight hours of appearance of discharge, 86 per cent. in those reporting from eight to twenty-four hours afterwards, and 60 per cent. in those reporting later. The system of abortive treatment varied in different stations, but the principle in practically all was to irrigate thoroughly with potassium permanganate and then inject an organic preparation of silver, such as 5 to 10 per cent. protosil, which was retained for some minutes. This operation was repeated once or twice daily for five days and the irrigation continued for a few days longer.

In cases where soldiers reported for disinfection more than twelve hours after exposure, a modified form of abortive treatment of gonorrhœa was adopted at the Australian depôts, on the principle that a single disinfection undertaken so long after exposure might not avert gonorrhœa, but that the case was in an ideal stage for the abortive method.

It is difficult to estimate the effect of the prophylactic stations on the venereal rate, since no record of the names of those disinfected was kept, and in any case it would have been almost impossible to trace the subsequent history of individual men. In certain stations, particularly Paris, where Captain Walker of the Canadian Army Medical Corps, established a disinfecting station and a distributing centre for packets of disinfectants at Pépinière barracks, the infections reported as contracted there appear to have fallen very remarkably, but reports as to places of infection were notoriously unreliable even when the officers in venereal disease hospitals had time to gather them. Assuming that a fall did occur, how much of it was due to skilled disinfection at the station and how much to self-disinfection is uncertain. At the Canadian Base Depôt in Havre, during the six months from November 1916 to April 1917 inclusive, a preventive depôt was instituted in consequence of the large amount of venereal disease apparently contracted there. Each man on return to barracks was questioned as to exposure to infection and, if he replied in the affirmative, was advised to have preventive treatment. Out of 5,153 who were so treated by skilled disinfection it is stated that none contracted venereal disease, while 49 known not to have submitted to disinfection were admitted to hospital. The record does not mention, however, what steps were taken to trace the later history of the men who submitted to disinfection. It is conceivable that, if their stay in the depôt was short, any disease might not have developed until they had arrived at another station.

Canadian Base Depôt, Havre.

Date.	Number of men passing through Canadian Base, and Permanent Staff.	Number of Treatments taken by Officers, N.C.O.s and Men.	Number of Men who developed V.D. after Treatment.	Total Number of Men admitted to Hospital with V.D. from Depot.*	Number of known Cases of V.D. of Men failing to report for Treatment.*
November 1916	13,959	155	0	119	9
December 1916	13,113	476	0	101	5
January 1917	5,113	542	0	83	8
February 1917	6,304	853	0	83	6
March 1917	7,204	1,492	0	69	12
April 1917	11,573	1,635	0	72	9
	57,266	5,153	0	527	49

* The number of those infected at Havre was not stated.

On the whole, the experience appears to have shown that disinfection by skilled attendants has some value as a protection against venereal disease. The American experience of the same method of prophylaxis was similar.

In the prevention of wastage by reason of admission to hospital for venereal disease, two measures, therefore, stand out as having given good results: (*a*) disinfection by skilled attendants, (*b*) abortive treatment of gonorrhœa; and it appears advisable that plans for both these measures should be considered in the preparation for war in future. The value of lectures is not demonstrable by any statistics, but it may be said in their favour that, before any measure of disinfection was adopted in the British army, the rate was lower during the war than before. The question of self-disinfection is so controversial and its discussion would occupy so much space that it cannot be dealt with here. Self-disinfection is commonly confused with disinfection by skilled attendants, and many of the arguments advanced in favour of the former have been based on results obtained when the latter has also been practised. The question will be decided only when garrisons are stable, not shifting as in the war, and when the rates of two units in the same town, granted the same amount of leave, worked equally hard and having much the same recreations, but one employing self-disinfection, the other not, have been compared with one another over a fairly long period.

Hospitals for Venereal Diseases.

For the most part special hospitals were established for the treatment of venereal disease, but in a few cases divisions or sections of general hospitals were utilized. The number of beds devoted to this work was gradually increased until at the date of the armistice there were in the United Kingdom 20 hospitals for venereal diseases only, accommodating about 11,000 beds, and 14 which had set apart about 1,500 beds for venereal disease cases. In France there were four large hospitals, in Havre, Calais, Etaples and Rouen, and four smaller hospitals, altogether accommodating about 9,000 beds. In Italy there were four hospitals, namely, at Bordighera, 650 beds; Genoa, 120 beds; Taranto, 175 beds; and Fienza, 10 to 20 beds. There were in Egypt about 1,000 beds in a division of a hospital, and in Salonika about 400 beds, making a total of approximately 23,900 beds set apart for venereal diseases in the British forces.

Internal Arrangements of Hospitals.—The successful treatment of large numbers of venereal cases depends greatly on the convenience of the arrangements. The number of cases allotted to each medical officer (200 to 250 or more in France) made it imperative that the arrangements should be such that a medical officer wasted no time over preliminaries.

It will be convenient to describe first the internal arrangements for treatment in No. 9 Stationary (later No. 39 General) Hospital, since this was the parent hospital in France, on which others were modelled and in the course of time all venereal disease hospitals in the United Kingdom adopted more or less the same principles.

In October 1914 the Officer Commanding No. 9 Stationary Hospital was ordered to establish a camp at Sanvic, Havre, for the reception and treatment of venereal disease cases occurring in the British Expeditionary Force. Up till then patients suffering from venereal disease had been received into general and stationary hospitals and shipped to England as soon as possible. The hospital was very soon in difficulties from the number of patients who crowded into it. At that

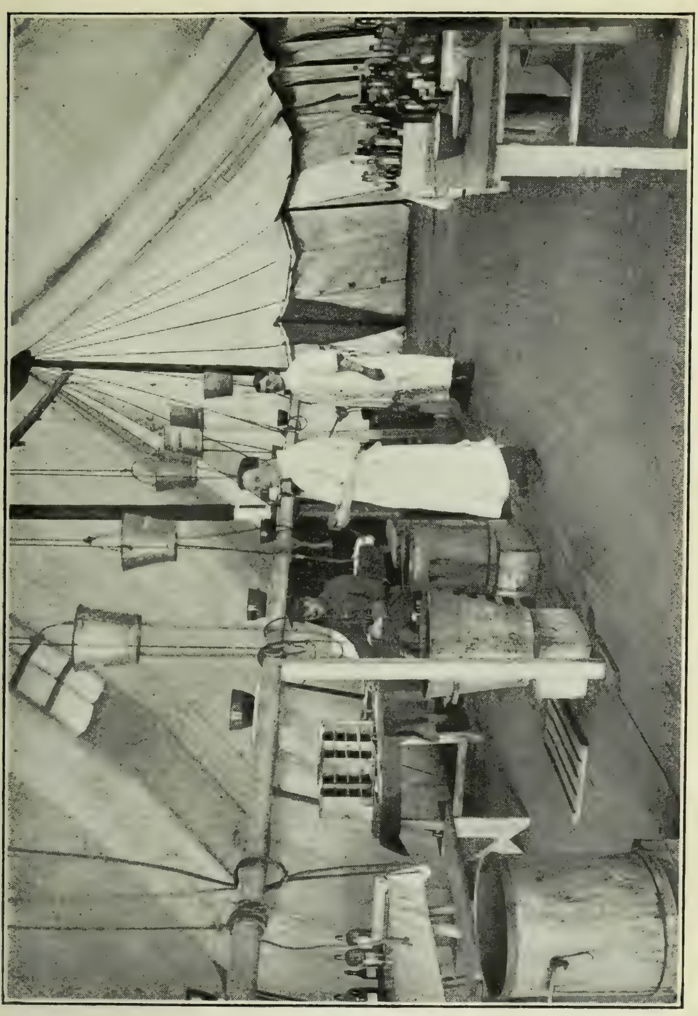

Fig. 1.—No. 9 Stationary Hospital. First arrangement for centralization of irrigation arrangements. Store tent fitted for irrigation of a gonorrhœa section (200–250 patients).

time it was intended that any surplus over 500 patients should be sent to England, but this intention was never carried out. When Major Harrison took over command of the hospital on 4th January, 1915, about 350 had been sent to England, but the number in hospital was 1,000. By that time a supply of salvarsan and neosalvarsan and some bacteriological apparatus had been received from England, but no use had been made of either. Every tent was packed with patients, save the

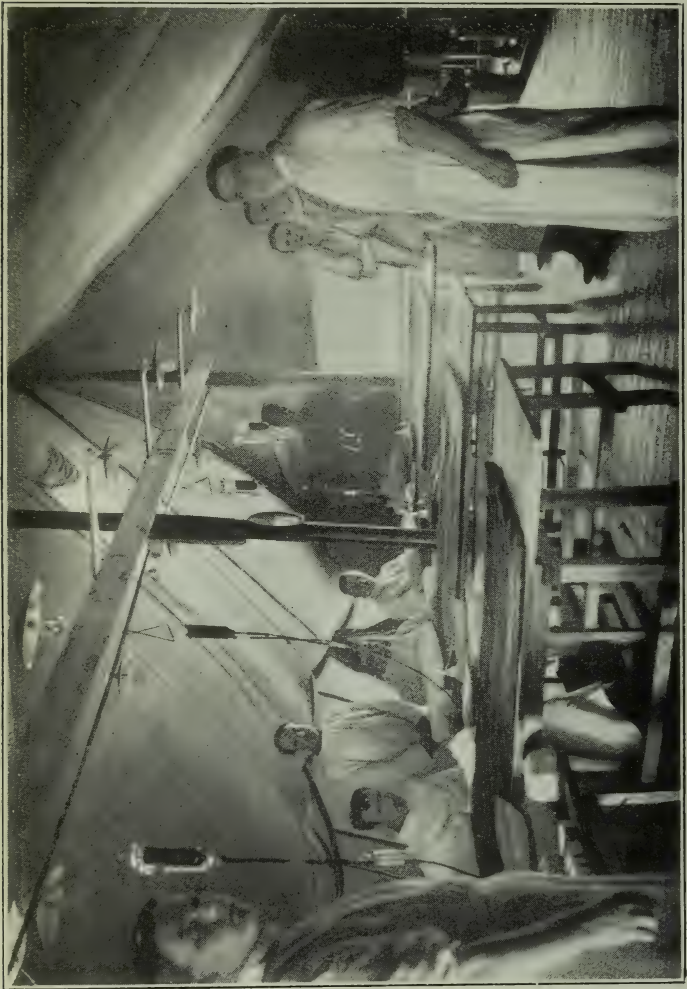

Fig. 2.—No. 9 Stationary Hospital. Hospital marquee fitted up for the administration of "606" to four patients at one time.

offices and stores, one small hospital marquee in which mercurial injections were being given, and about six bell tents in each of which was hung an irrigator bucket. Patients were being examined in the sleeping marquees, and the treatment arrangements were chaotic, a result to be expected from the fact that none of the staff had any previous experience of the treatment of venereal disease. The difficulties of management were not lightened by the badness of the site, which was deep in mud. Paths were being made, but early in January 1915 anyone who left a path sank halfway to the knees. A specialist in dermatology had given the opinion that intravenous injections should not be given in such surroundings.

The following changes were instituted at once and were in full force by the end of January 1915 :—

(1) The hospital was divided into two divisions, gonorrhœa and syphilis, including in the latter suspected syphilis and soft chancre. These again were divided into sections of 200 to 250 beds each under the charge of a medical officer.

(2) In each section a marquee was fitted for examination and treatment, those in the gonorrhœa division having bucket irrigators and large iron tubs to receive the overflow irrigating fluid. (Fig. 1).

(3) In each section a marquee was fitted for complicated cases requiring nursing, so that these could be under the care of a good orderly, and the medical officer had his patients requiring special attention collected in one place, not scattered about in different marquees.

(4) A marquee was fitted up for injection of anti-syphilitic remedies. This served also as a consultation centre. (Figs. 2 and 3.)

(5) A marquee was fitted up as a laboratory.

(6) A treatment card, which subsequently was adopted as an Army form,* was introduced.

(7) A system was established by which every patient to whom it was proposed to give anti-syphilitic remedies was first seen by the officer in charge of the division. This was necessary as, with the exception of two officers of the regular R.A.M.C., hardly any of the medical officers who joined the hospital had any previous experience of venereal disease, and as they were constantly being changed it was safer to check their diagnoses.

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* A.F.W. 3497.

The regular consultation started each day at 9 a.m. A medical officer who considered that a patient was syphilitic sent him the following day to the consultation marquee with the notes of his case. If the officer in command of the division did not agree, he made his comments on the treatment card when referring the case for further observation. If the diagnosis was confirmed, the case was registered, and the programme of treatment made out on a special card kept in

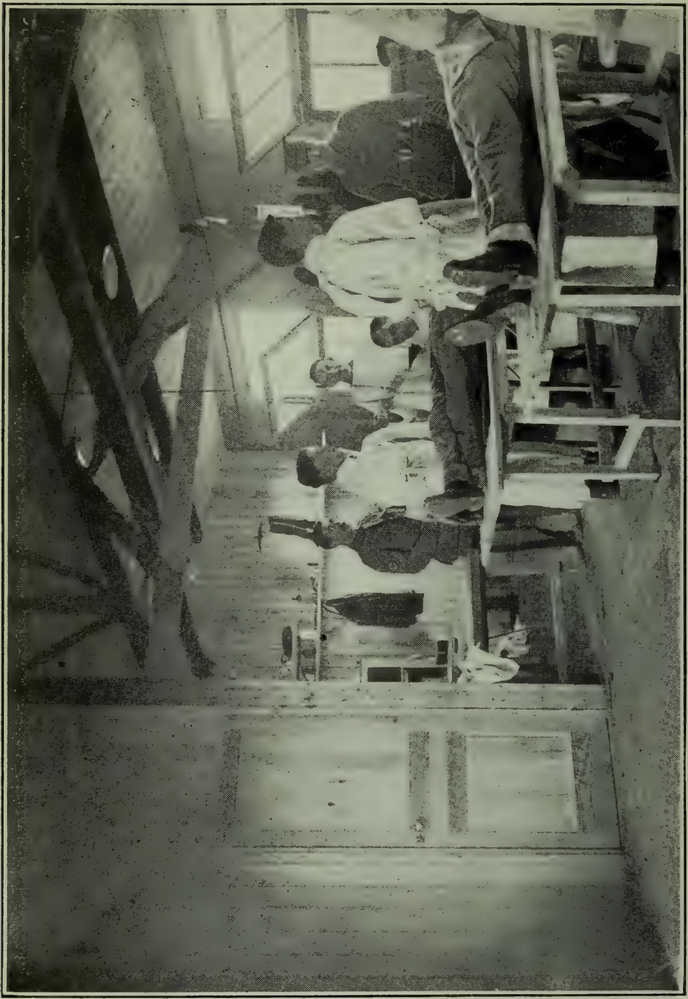

Fig. 3.—No. 9 Stationary Hospital. Hut for injections of "606."

the central treatment room. Thereafter the patient's anti-syphilitic treatment was carried out centrally. His own medical officer looked after him generally, but the patient, in common with others, was warned through his ward-master to appear for his injections as they became due by a messenger from the central treatment room.

The staff was strengthened by the arrival of Captain A. F. Dawson on 6th January, 1915, and of Captain C. F. White on 16th January. Captain Dawson, being a specialist in bacteriology of the regular R.A.M.C., was put in charge of the laboratory, and Captain White, a specialist in dermatology, also of the regular R.A.M.C., took over supervision of the syphilis division from Major Harrison. The comparative immunity from trouble resulting from arsenobenzol treatment which was enjoyed by the hospital throughout the war was due very largely to the latter officer's careful supervision. For many months he prepared all the "606" himself, and trained newcomers in the art of veni-puncture, and it was not until a staff of reliable officers had been collected that these duties were even temporarily delegated to another officer.

Throughout the war practically the same system as sketched above was followed. In time huts replaced the marquees used for treatment and for the laboratory. Troughs were instituted in gonorrhœa treatment huts in place of the tubs, while enamelled iron pails replaced zinc buckets as irrigators, but these were only improvements in detail. It may be added that, in regard to the internal arrangement of treatment huts, no fixed plan was at first evolved. Medical officers took over the empty shells, and having somehow obtained materials, put up partitions and fitted the huts internally according to their individual ideas, employing patients' labour. Alterations were frequently made until a pattern was evolved which was most efficient.

The record of this hospital shows the following facts of interest. In January and February 1915, whilst the hospital was being organized, and before the effect of arsenobenzol treatment had begun to tell on the duration of syphilis cases in hospital, 925 venereal disease cases were evacuated to England. In the remaining months of 1915, 326 cases were sent, and thereafter the number of cases invalided to England was as follows: 1916, 127; 1917, 62; 1918, 264—making a total of 453. The number of patients returned to duty from January 1915 to January 1919 was as follows: 15,557 in 1915, 22,089 in 1916, 18,292 in 1917, and 14,912 in 1918, making a total of 70,850. The number of arsenobenzol injections in the same period was 119,727 and the deaths 12.

The system outlined above was adopted in principle by the venereal disease hospitals subsequently established in France. These were, in fact, started by officers who had been trained in this hospital. In the United Kingdom, also, much the same system was gradually adopted.

Disposal of Cases.—At No. 9 Stationary Hospital syphilitic patients whose lesions had healed were sent to a special convalescent camp adjoining the hospital, where they performed various duties and attended the hospital for continuation of treatment, as outlined below. Gonorrhœa cases were also sent to this camp when they had reached the stage where daily treatment was not required, or when it was thought advisable to test them for cure by suspending treatment and giving them heavy fatigues. The great majority of gonorrhœa cases were, however, returned to duty from the hospital. In the United Kingdom some hospitals were able to dispose of the syphilis convalescents as above. Others, owing to their situation, had to retain them in hospital throughout the course of treatment. All gonorrhœa cases in the United Kingdom hospitals were retained in hospitals throughout.

In September 1917 it was decided to send gonorrhœa convalescents to replace permanent base men as stretcher-bearers and general duty men in the casualty clearing stations. Arrangements were made for their further treatment there, and altogether 3,950 were disposed of in this manner.

There can be no question that the principle of keeping soldiers suffering from venereal disease in hospital for as short a time as is compatible with safety to others and with their own treatment is sound. The great evil of large venereal disease hospitals is the lack of occupation provided for numbers of men who do not feel ill. They become slack in mind and body, and their disease becomes an obsession which definitely interferes with their recovery. In the case of syphilis it is almost always possible to discharge patients to useful duties under arrangements for continuation of their treatment on a plan which can be easily laid down. In gonorrhœa it is not so simple, because the apparatus required for the treatment of chronic gonorrhœa is complicated; the treatment is individual, and considerable skill and resource are necessary on the part of the operator. The continuation treatment of syphilis could be carried out in a bell tent, but chronic gonorrhœa requires the surroundings of an operating theatre.

The problem of gonorrhœa is a very difficult one because, while interesting occupation largely in the fresh air is a powerful factor in the cure of chronic gonorrhœa, very many cases require some instrumental treatment, which cannot easily be arranged if the patients are distributed widely. Probably the most economical plan would be to treat acute gonorrhœa in large hospitals as far forward on lines of communication as possible, and to distribute the chronic cases in areas remote from towns, but so situated that they could be brought weekly in batches to one or more central stations well fitted for instrumental treatment. The necessary skilled treatment being required only about once a week, such an arrangement would permit of these patients being employed in battle. Besides the considerations mentioned above, provision should always be made for what may be called the emergency treatment of syphilis and gonorrhœa. Delay in commencing treatment means rapidly increasing wastage from venereal disease, not only because of the actual time lost in the beginning, but because every day's delay lengthens the duration of the necessary treatment. The bacteriological diagnosis of early syphilis is easily within the competence of a mobile laboratory, and the injection of an arsenobenzol compound, which will stop the process for a week whilst the patient is being transported to a central hospital, is safe and easy. The immediate treatment of acute gonorrhœa requires comparatively simple appliances, which could be part of every field ambulance, casualty clearing station and hospital train, since it occupies little space, and thus the continuous treatment of gonorrhœa could be arranged from the front to the central venereal disease hospital. During the war Lieut.-Colonel E. T. Burke, R.A.M.C.(S.R.), showed the practicability of such a scheme by treating gonorrhœa in his field ambulance.

Treatment of Syphilis.

The course of anti-syphilitic treatment adopted at first in France was based on the experience gained in the investigation of salvarsan at Rochester Row from 1910 to 1914. The plan adopted was ruled by the following considerations :—

(1) It was important that the period of treatment should be as short as was consistent with a reasonable expectation of a high percentage of cures, since naturally the longer the duration of treatment the greater the wastage from syphilis.

(2) The latest course of treatment investigated at Rochester Row before the war, viz., one dose of 0·6 grm. "606"

followed by five injections of mercury, one more injection of 0·6 grm. "606," five more of mercury, and a final injection of 0·6 grm. "606," had been followed by about 25 per cent. of relapses, clinical and serological, within one year, and did not therefore appear to be sufficient. It was determined to increase the total amount of "606" from 1·8 grm. to 2·4 grm.

(3) The injection of full doses of "606" at intervals of less than two weeks had been followed, in other hands, by death with cerebral symptoms in a proportion of cases which increased with the shortness of the interval between injections. It was felt that such tragedies must be avoided, since even a small proportion of fatalities would make a large total amongst the numbers treated during the war.

In order safely to administer a total of 2·4 grm. "606" in as short a time as possible, and yet avoid these cerebral tragedies, Major Harrison decided to give eight injections of 0·3 grm. each in twenty-eight days. The expectation that by administering the course in small doses cerebral side effects would be avoided was justified, since only one death of the kind indicated occurred after the 125,078 injections given in the venereal hospital at Havre from January 1915 to June 1919. Other hospitals enjoyed a similar immunity, since only eight such cases came to notice in a series of about 100,000 cases of syphilis treated with about 800,000 injections.

The arsenobenzol injections were accompanied by injections of mercury in one course.

Trouble arose, however, from another source which had not been experienced in the British military hospitals before the war. During the first ten months of 1915 a certain number of cases of erythema and one case of severe dermatitis had occurred in France amongst the arsenobenzol treated cases, but these had not caused any particular anxiety. In November 1915, however, dermatitis appeared to become rather more prevalent, and during the winter some very severe cases occurred, resulting in seven deaths in No. 9 Stationary Hospital. The long period of incubation of some of these cases in which symptoms commenced a month after the termination of the course showed clearly that even the most careful watching of the cases for first signs of intolerance which was instituted after the first case of dermatitis was not a sufficient safeguard against this complication. Accordingly intervals of rest were introduced into the course in order that time could be given for intolerance in susceptible patients to declare itself.

In November 1915 the course in France was lengthened to forty-two days, the first four injections of 0·3 grm. being given in fourteen days, then a rest of fourteen days, followed by four injections in the last fourteen days. This was again modified in the following month by giving three injections the first week ; two weeks' rest ; two injections in the next four days ; two weeks' rest ; and three injections in the last week. Although the proportion of cases showing signs of skin intolerance was not greatly reduced by this modification, the type became distinctly milder. As it appeared also that cases of dermatitis were particularly susceptible to cold, developing pneumonia as easily as cases of burn of the second degree, which they resembled, all patients showing even a mild erythema were promptly removed from their marquees to a hut, where they could be kept warm. That these measures, in addition to the most stringent care in watching for signs of intolerance, such as anæmia, malaise and loss of weight, as well as skin disturbance, were successful, is shown by the fact that, after the winter of 1915–1916, No. 9 Stationary Hospital lost only five out of the 16,000 cases treated with 82,157 injections of arsenobenzol compounds. Two of these were cases of dermatitis, one pernicious anæmia, one toxæmia, and one empyema. None of the last three suffered from either jaundice or dermatitis.

The mercurial treatment given at the same time, was as follows. At first six injections were given. Then in September 1915 the number was reduced to five on account of stomatitis. It was again increased to seven when the course was lengthened to forty-two days.

In the United Kingdom the course of treatment adopted as routine in 1915 was five injections of 0·3 grm. salvarsan and five of mercury, in one month of treatment.

In May 1916 this course was increased in England as follows:—

Course of Treatment commenced 16*th May. Home Forces.*

Day of Treatment.	Salvarsan or its equivalent.	Mercury.
1st	0·3 grm.	gr. i
4th	0·3 ,,	—
8th	0·3 ,,	gr. i
15th	—	gr. i
22nd	0·4 ,,	gr. i
29th	0·5 ,,	gr. i
36th	—	gr. i
43rd	0·5 ,,	gr. i
50th	0·5 ,,	gr. i
Totals	2·8 grm.	gr. viii

Course of Treatment—cont.

Day of
Treatment.
52nd : Blood test.

If the blood test is negative, treatment to be suspended and blood tests repeated at intervals of three months if practicable. If subsequently found to be positive, the above course to be given and a follow-up course as below. If the blood test on the 52nd day gives a positive reaction, continue as below.

54th to 68th day : Potassium iodide.

	Salvarsan.	Mercury.
69th	0·3 grm.	gr. i
76th	0·4 „	gr. i
83rd	0·5 „	gr. i

If still positive at the end of this time, advise chronic mercurial treatment.

Early in 1918 the course was modified as follows :—

Routine Course for Ordinary Fresh Cases of Syphilis (to be interrupted in the event of Dermatitis, Jaundice or other signs of intolerance supervening).

Each patient to be carefully scrutinized for signs of stomatitis or general malaise, his weight to be taken and urine tested for albumin before each injection.

Day of Treatment.	Alternative Arsenical Preparations and methods of administration.			Mercury.
	Intravenously.		Intramuscularly, or into deep Subcutaneous Tissue.	Intramuscularly.
	" 606 "*	or " 914 "†	or " 914 "	Mercurial Cream.
1st	0·3 grm.	0·45 grm.	0·45 grm.	gr. i
8th	0·3 „	0·45 „	0·45 „	gr. i
15th	0·3 „	0·45 „	0·6 „	gr. i
22nd	—	—	—	gr. i
29th	0·4 „	0·6 „	0·6 „	gr. i
36th	0·4 „	0·6 „	0·6 „	gr. i
43rd	—	—	—	—
50th	0·4 „	0·6 „	0·6 „	gr. i
57th	0·5 „	0·75 „	0·6 „	—

59th : Blood test. If positive or doubtful, continue as below.
61st to 75th day : Potassium iodide.

82nd	0·3 grm.	0·45 grm.	0·6 grm.	—
92nd	0·4 „	0·6 „	0·6 „	—

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* The terms " salvarsan " and " 606 " refer to dioxydiamidoarsenobenzol dihydrochloride, sold under various trade names such as salvarsan, arsenobenzol (billon), arsenobillon, kharsivan and diarsenol.

† The term " 914 " refers to dioxydiamidoarsenobenzol monomethylene sulphoxylate of soda, a preparation with about two-thirds the arsenical content of " 606 " and sold as neosalvarsan, novarsenobenzol (billon), novarsenobillon, neokharsivan or neodiarsenol, according to the maker.

If blood is negative on the fifty-ninth day, suspend treatment, and, if practicable, repeat blood tests at intervals of three months, but do not hold back from draft overseas.

In tertiary cases, provided that all symptoms have then disappeared, return to duty on fifty-eighth day regardless of Wassermann.

The above lines of treatment do not apply to that of syphilis of the central nervous system, cases of which should be treated on individual lines. The principle in such cases is to commence cautiously, increasing the individual dose gradually to 0·3 grm. "606" or equivalent in "914," and prolonging the course until the patient has received 4 to 5 grm. A very successful method is to give a weekly intravenous injection of "606" and a weekly intramuscular of "914"—0·3 grm. in each case.

The first of these two courses was attended by a moderate amount of dermatitis and jaundice, and was modified as shown in the second because in two Imperial hospitals in 1917 and early 1918 small outbreaks of acute yellow atrophy had occurred amongst arsenobenzol treated cases, resulting in nineteen deaths, and eight similar deaths occurred in three hospitals of the Dominion forces and two other Imperial hospitals for the treatment of venereal disease. It was felt that, although the first course of treatment had been followed by no such untoward event for over a year and none of the other hospitals had experienced similar cases, the arsenobenzol treatment might be a strong factor, and pending an investigation it would be safer to modify the course. As shown, this was reduced by 0·2 grm. "606" and extended by one week. Two cases of acute yellow atrophy occurred in military venereal disease hospitals in the United Kingdom after the introduction of the above course. One had been treated with luargol; the other had received only 1·05 grm. of "914" by three injections in twenty-three days. Except for these, no report of acute yellow atrophy was subsequently received from any military hospital up to December 1919.

The modification of the course as shown above was followed by a definite reduction in the amount of dermatitis and of ordinary jaundice. Thus the Lichfield Central Hospital had 11 cases of dermatitis and 12 of mild jaundice in 19,100 injections of the first course (2·8 grm. in fifty days), and only two of each in 11,734 injections under the later course (2·6 grm. in fifty-seven days). This experience was similar to that of other military hospitals, and it seems reasonable to suppose that 2·6 grm. of "606" or 3·9 grm. of "914" is about as much arsenobenzol treatment as should be given to an average case in eight weeks.

In France, from March to April 1915, the course of treatment had to be cut down to six injections of 0·3 grm., with mercury, in twenty-two days owing to shortage of supplies. In November

1916, the course outlined above for the United Kingdom was adopted in No. 9 Stationary Hospital (the designation of which had then been altered to No. 39 General Hospital), but omitting the first mercurial injection to allow of dental treatment. Later a course of four intravenous injections of "606," followed by four deep subcutaneous injections of "914," was introduced by Major W. Peyton at No. 1 Stationary Hospital and subsequently adopted by Major White in No. 39 General Hospital. The method of administration of "914" by deep subcutaneous or intramuscular injection had been investigated by Mills and Harrison at Rochester Row and by White at No. 39 General Hospital in parallel series of cases and the results in the two hospitals had agreed in demonstrating the great superiority of this method from the point of view of therapeutic effect. Subsequently this method of administration was largely employed at Rochester Row and a few other hospitals in the United Kingdom, as well as at No. 39 General and No. 1 Stationary Hospitals in France.

Other Remedies for Syphilis.—In January 1916 a new compound for the treatment of syphilis, namely, di-ortho-amino-thiobenzene, sold as intramine, was introduced by McDonagh. He claimed for it that its use in conjunction with salvarsan gave results greatly superior to those which were being obtained. Subsequently Spence also reported favourably on the combination, especially in late cases. At a later date McDonagh introduced ferrivine, a stable organic compound of iron which was stated to be non-toxic, though it was admitted that 200 to 300 c.c. occasionally caused typical shock. Harrison and Mills found that intramine injected intramuscularly was extremely painful and liable to cause sloughing of tissues; ferrivine was dangerous when injected intravenously, and neither had any effect in causing spirochætes to disappear or syphilitic lesions to heal. A polemical correspondence followed in the medical papers. On 7th October, 1916, McDonagh announced that ferrivine was apt to form the hydroxide on reaching the blood-stream, and so cause shock. For this reason he had had to add a protective to preserve its colloid state, but unfortunately this had reduced its therapeutic power. It would be necessary to prepare a compound with the iron more firmly united to the benzine ring. When this was achieved he was confident that, with the joint use of intramine, the treatment of syphilis would be more successful and less dangerous than it is with salvarsan and its substitutes. In August 1917

McDonagh, at No. 39 General Hospital, suggested a scheme of treatment as follows :—

For early cases of syphilis :—

1st day.	100 c.c. colloidal iodine.	Intravenously.
2nd ,,	50–100 c.c. ferrivine.	
4th ,,	0·6 grm. "606."	
5th ,,	Colloidal mercury, 1 per cent.	
6th ,,	100 c.c. intramine.	
8th ,,	15 c.c. colloidal mercury.	
9th ,,	100 c.c. intramine.	
12th ,,	0·6 grm. "606."	

For late tertiary cases :—

1st day.	100 c.c. colloidal iodine.	Intravenously.
2nd ,,	100 c.c. intramine.	
4th ,,	100 c.c. intramine.	
6th ,,	Colloidal mercury.	
7th ,,	100 c.c. intramine.	

The time was not a suitable one at which to make such a drastic alteration of the routine treatment of syphilis as that suggested above, since the change would affect the efficiency of very large numbers of soldiers, and its results could not be judged for many months. With regard to the first of these courses, it was felt that, without the other remedies, two full doses of "606" would cause symptoms to disappear, but experience had shown that two full doses of "606" had not been followed by permanence of cure in a sufficiently large percentage of cases and that there was no evidence to show that the additional remedies would give improved results from this point of view. Eventually a small series of cases, chosen by McDonagh, was treated by him as follows on the lines suggested above but without ferrivine, which he omitted, and without "606," the injections being given intravenously:—

1st day.	Colloidal iodine	100 c.c.
2nd ,,	,, mercury (1 per cent)	6 ,,
4th ,,	,, ,, ,,	10 ,,
5th ,,	Intramine	100 ,,
7th ,,	Colloidal mercury	7 ,,
9th ,,	,, ,,	5 ,,
15th ,,	Intramine	100 ,,

Two primary and six secondary cases were treated without effect.

Two tertiary cases were treated without effect on the following plan :—

1st day.	Colloidal iodine	100 c.c.
2nd ,,	Intramine	100 ,,
4th ,,	,,	100 ,,
6th ,,	Colloidal mercury	7 ,,
8th ,,	,, ,,	7 ,,
13th ,,	Intramine	100 ,,

Side effects appear to have been somewhat severe. Diarrhœa and vomiting followed the mercurial injections in four cases, one patient becoming collapsed in the latrine. Stomatitis occurred in three cases, intramine having apparently failed to prevent or cure this complication. The experiment also resulted in seventeen thrombosed veins, and in five cases the arm is reported to have become very painful and swollen.

With regard to the effect of intramine in improving the therapeutic value of the routine course of treatment, an investigation was carried out at the Lichfield Central and the Cherry Hinton military hospitals. A series of 258 primary and secondary cases was treated by the routine course of 2·8 grm. "606" with mercury in fifty days; 258 similar cases were treated as had been suggested by McDonagh in the following terms:—

"During the ordinary course of '606,' two intramuscular injections of intramine should be given, the first 2·5 c.c. after the third injection, and, the second, 5 c.c. four days after the last injection. In all recurrent and late cases of syphilis an initial dose of intramine, 2·5 c.c., should be given; then two or three injections of '606'; then 5 c.c. of intramine, and finally one or two injections of '606.'

"In all cases of arsenical intoxication 5 c.c. of intramine should be injected at once, and repeated in a few weeks' time if thought necessary."

The results were as follows:—

	Intramine Series.			Control Series.		
	Positive	Negative	Doubtful	Positive	Negative	Doubtful
Wassermann reaction after fourth injection of "606" ..	117	100	41	118	97	43
Wassermann reaction after seventh injection of "606"	42	206	10	38	207	13
Toxic effects ..	One dermatitis. One mild jaundice.			One mild jaundice.		

Thus, no difference was apparent between the two series.

In August 1917, and subsequently in No. 51 General Hospital, the effect of intramine was investigated on a variety of skin diseases, including dermatitis following arsenobenzol injections. The report was, on the whole, favourable, and subsequent experience has shown that intramine will often abort a case of arsenobenzol dermatitis.

Danysz's preparation, luargol, or " 102," a combination of " 606 " with antimony sulphate and silver bromide, was tested extensively at a number of hospitals and found to have the therapeutic properties claimed for it by its author, namely, that it is approximately twice as powerful as " 606." The first preparation had to be alkalized and frequently caused thrombosis of injected veins. It was succeeded by the sodium compound, disodo-luargol, an emery-coloured powder which required only solution in water and caused no thrombosis. This compound appears to be no longer on the market.

Galyl,* the preparation introduced by Monneyrat in 1913, was used considerably in military hospitals up to 1916, but gradually dropped out of use. The general opinion was that it was followed by a higher percentage of relapses than the other preparations.

" Silbersalvarsan," a combination of " 606 " and silver, and " 1495 " or " sulphoxylate," a stable arsenobenzol preparation sold in ampoules already dissolved and ready for use, both of them prepared by Ehrlich's successor Kolle, were tested after the armistice at Rochester Row. Silbersalvarsan appears to be similar in therapeutic power to luargol, while " 1495 " seems to be slower in effect than " 914." The samples were procured by the Medical Research Committee.

Supplies of Arsenobenzol Compounds.—Owing to salvarsan being a German product, supplies of arsenobenzol compounds ran very short in the early stages of the war. In England, Messrs. Burroughs & Wellcome stepped into the breach by producing a chemically identical compound known as kharsivan, and in France, Messrs. Poulenc Frères made arsenobenzol (billon), and novarsenobenzol (billon), whilst in both countries galyl was also largely employed. At a later stage of the war a " 606 " preparation, diarsenol, was produced in Canada and arsenobillon, novarsenobillon and neokharsivan began to be made in England. On account of patent rights, all arsenobenzol preparations, except galyl, were sold in England under Board of Trade licence, which required that the compound should have passed certain biological tests applied by the Medical Research Committee. The fixing of a biological standard was a task of considerable difficulty as it was found that the published standard of the Germans was unreliable. The standard required in England varied slightly from time to time, but eventually was fixed at survival of a rabbit after intravenous injection of 0·12 grm. "606" per kgm., and 0·20 grm. per kgm. in the case of "914." Rabbits were used for the biological testing of arsenobenzol compounds throughout the war, but subsequently mice were found to be more satisfactory and the following quotation from No. 44 of the Medical Research Committee's Special Report Series indicates the test doses and standards by which a sample of arsenobenzol compound is considered as fit for sale.

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* Tetraoxydiphosphaminodiarsenobenzene.

"For '606':—

Rabbit	0·12 grm.	per kgm.	
Mouse	0·125 ,,	,,	(*i.e.*, mg. per grm.)
Rat	0·08 ,,	,,	(*i.e.*, mg. per grm.)

"At least five animals should be used for a test. In the case of the rabbit, which is relatively little liable to the acute action, no death should occur if the injection is made slowly and uniformly, the whole injection occupying not less than five minutes. In the case of the mouse, one death in five should not disqualify the preparation. If two deaths in five occur, the preparation should be retested on a higher dose—0·15 mg. per grm. If the majority of mice tolerate this dose the preparation may be considered satisfactory, but should otherwise be rejected. If more than two deaths in five occur on the standard dose of 0·125 mg. per grm., the preparation should be rejected forthwith.

"If rats are used the method of interpreting results suggested in the case of mice may also be applied, namely, one death in five on the standard dose of 0·08 grm. per kgm. should not disqualify; two deaths in five should lead to retest on the higher dose of 0·1 grm. per kgm., and more than two deaths in five on the standard dose should disqualify immediately.

"For '914' the following intravenous doses may be used on the same principle. Injection should be made in a strong solution (10 per cent. or more):—

Rabbit	0·2 grm. per kgm.
Mouse	0·3 mg. per grm.
Rat	0·18 mg. per grm.

The rejection of many batches by the test on rabbits made it exceedingly difficult for the manufacturers to comply with the demand in England, whilst the French supplies were inadequate to the requirements of No. 9 Stationary Hospital. Fortunately in July 1915 Harrison discovered about 10,000 doses of German salvarsan sequestrated at Creil, and after some negotiations bought it for the use of the British army, subject to the biological test proving satisfactory. The testing was carried out at No. 9 Stationary Hospital and results confirmed by the Medical Research Committee. This windfall and the release from military service of a French chemist, kindly secured by

Méd.-Inspecteur Chavasse, the Director-General of the Medical Service of the French Armies, saved the situation, and No. 9 Stationary Hospital not only became independent of supplies of " 606 " from England but sent to the Army Medical Stores at Woolwich some thousands of doses.

Toxic Effects of Arsenobenzol Treatment.—These have been referred to above in connexion with the modifications of treatment which were introduced in the United Kingdom. In order to arrive at an estimate of the percentage of such toxic effects as dermatitis and jaundice in the United Kingdom a scrutiny of 39,377 treatment cards was carried out. This disclosed 370, or 0·9 per cent. of dermatitis, varying in severity from transient erythema to exfoliative dermatitis, with 18 deaths, and 221 cases of jaundice with 24 deaths. In France, White's scrutiny of 33,256 case cards showed 316 cases of dermatitis, or 0·95 per cent., and 107 cases of jaundice, or 0·32 per cent. There were 50 deaths in this series, of which 18 were certainly due to dermatitis and 8 to jaundice. The cause of death in the remainder is difficult to determine from the case records. No. 39 General Hospital had no case of acute yellow atrophy amongst its contribution of 18,500 cases to the series. Two cases of acute yellow atrophy occurred in No. 1 Stationary Hospital, but one had received no arsenobenzol treatment there and the other only three injections of 0·2 grm. arsenobenzol. This patient was jaundiced when treatment commenced and there seems to be little doubt that he was a case of syphilitic parenchymatous degeneration of the liver.

The outbreak of acute yellow atrophy in the Cherry Hinton military hospital in 1917–18 led to the formation, by the Medical Research Committee, of a " Special Committee upon the Manufacture, Biological Testing and Clinical Administration of Salvarsan and of its Substitutes." This committee, composed of Sir Humphry Rolleston (Chairman) ; Professor F. W. Andrewes, Professor W. Bulloch, Dr. H. H. Dale, Colonel L. W. Harrison, R.A.M.C., and Dr. F. J. H. Coutts as Secretary, commenced its sittings in February 1918. In July 1918 Surg.-Commander D. W. Hewitt, R.N., was added to the committee and acted until April 1919, and in September 1918 Major C. F. White, R.A.M.C., was made corresponding member in France. The committee enquired into all matters connected with arsenobenzol compounds and issued a preliminary report in 1919 dealing with the subject generally. The second report published in 1922 dealt more particularly with toxic effects. After reviewing the voluminous literature on the subject, this report dealt with the incidence of toxic effects in the British forces and came to the following general conclusions: (1) Vaso-motor effects are probably a result of the physical state of the remedy when injected. (2) Dermatitis is arsenical in origin, and there is a fairly close connection between the incidence of this complication and intensity of treatment. (3) The relation between arsenobenzol treatment and jaundice cannot be defined exactly, but its close similarity to the liver disturbance consequent on trinitrotoluene and toluylenediamine poisoning points to the organic complex of arsenobenzol as being to some extent responsible. The committee's review showed that outbreaks similar to that at Cherry Hinton had occurred in Germany during the war without any special change in remedy or technique, and that the reason remained unexplained. The question of an additional factor, such as microbial infection, suggested by Professor Stuart McDonald and others, was discussed but left open. At the same time the committee could not escape the conviction that there is a connection between intensity of treatment and the incidence of jaundice, the practice at Cherry Hinton having been to give 2·8 grm. "606" in forty-two instead of the fifty days recommended in the first of the courses outlined above.

The committee also enquired into the causation of a peculiar outbreak of illness which occurred amongst soldiers treated with "606" at Portobello, and resulted in eight deaths. It had been found by Professor A. C. O'Sullivan that the organs of those patients were full of malarial parasites, though only one was known to have served in tropical countries. Professor O'Sullivan's opinion was that the infection had been conveyed from one or more carriers to the others through the apparatus for injecting "606," the blood of the carrier regurgitating into the last segment of the tubing, remaining in crevices there, and being washed into the next patient's vein. The committee agreed that the deaths were due to malaria and had no reason to dissent from Professor O'Sullivan's view as to the mode of infection.

Therapeutic Results.—The therapeutic results of treatment applied during the war could be estimated only by the incidence of clinical relapse, since it was not possible in any but a small percentage of cases to bring the patients back for blood tests. In 1918 a scrutiny of 35,083 case cards, of which 10,000 were in No. 39 General Hospital and the remainder in various military hospitals in the United Kingdom, revealed 387, or 1·1 per cent., to be cases of clinical relapse after receiving 2·4 grm. or more of " 606," with 7 to 8 gr. of mercury by injection. This cannot be taken to indicate anything but approximately the result of administering this amount of " 606 " since the proportion of cases in the army which received this amount of treatment to that which received other amounts was not known. It is known only that by 1918 they were by far the most numerous. Besides the 387 relapses noted above, 219, related as indicated to a much smaller total of cases, had received less than 2·4 grm. of " 606 " and 547 had received only mercurial treatment. White's analysis of 18,500 cases treated in No. 39 General Hospital up to the end of 1918 showed 259, or 1·4 per cent., which had been treated there and had received therefore, 2·4 grm. of " 606," and 375 which had received less than this amount of treatment.

It is interesting to surmise what would have been the result of such a scrutiny as the above had purely mercurial treatment been the routine. In 1913 Harrison made a study of 371 syphilis case sheets of soldiers who had been treated regularly with mercury and found that 151 had been readmitted once for clinical relapse, 115 twice, and 49 three times during the first year, making at least 899 admissions to hospital for 351 cases. It seems reasonable to suppose that, under a purely mercurial system of treatment, a scrutiny of cards during the war would have revealed at least 50 per cent. of the cases of syphilis to be relapses.

Treatment of Chancroid.

Considerable attention was paid to the treatment of chancroid and its chief complication, bubo, because although they form only a small proportion of all venereal diseases, individual cases may prove very intractable. The practice varied greatly, but there was fairly general agreement on the following principles :—

(1) Caustic and cautery applications to the sore, as well as iodoform, are unnecessary and often harmful.

(2) Local applications should, if possible, not be antiseptic, in order that *Spironema pallidum* may be discovered early if the sore be of the mixed variety.

(3) The application of ointments, which interfere with drainage, often results in bubo.

(4) The application of powdered sulphur, as suggested by C. H. Mills at Rochester Row, is valuable. The sulphur is

rubbed in frequently with the tip of the finger and is not allowed to become sodden.

(5) Soaking in eusol, chloramine T, or hypertonic saline, followed by wet dressings of the same solutions, are valuable even in phagedæna, and will often turn the scale against a commencing bubo.

(6) Aspiration of buboes followed by injection of electrargol, tincture of iodine in water (1 in 20), or iodoform in glycerine (50 per cent.), is sufficient if undertaken before the skin has become too thin, and two or three aspirations are valuable as a preliminary to other measures.

(7) If aspiration fails, a small vertical incision at the lower pole of the bubo and the insertion of a small wick of gauze succeed far better than large open incision.

Treatment of Gonorrhœa.

The routine method adopted in all hospitals was irrigation of the urethra with potassium permanganate solution 1 : 8,000 to 1 : 4,000 twice daily during the acute stages. The irrigation was usually carried out by the patient after instruction. Chronic cases were treated by dilatation, prostatic massage, etc., on well-established lines.

Some attempts were made to discover a specific which, absorbed into the blood stream, would destroy the gonococcus. The administration of cinnamon oil by mouth to 200 cases failed to produce any benefit. The intramuscular injection of mercurial compounds was suggested by B. L. Wright, who claimed to have cured his cases in ten days by this method. Some support for Wright's statement had been afforded in Havre by the behaviour of those gonorrhœa cases who had suffered also from syphilis and had been subjected to the routine arsenobenzol treatment. It had been noted that a noticeable proportion of these cases were " dry " at the end of twenty-eight days. The apparently good result had been thought to be due possibly to arsenobenzol injections, and a certain number of chronic cases had been treated by arsenobenzol. This had proved without effect, and the arsenobenzol treatment of gonorrhœa cases had been dropped. The paper by Wright suggested the possibility that it was the mercurial treatment which had been responsible for the quick recovery of these cases of mixed gonorrhœa and syphilis, and a careful trial was made of the treatment. The procedure was to inject 100 mgm. succinimide of mercury every third day for about three doses.

The injections were well tolerated on the whole, though a few patients developed transient colitis. At first the results appeared to be exceedingly good. Large numbers of patients were free from discharge in a few days. Thus, three weeks after commencement of the treatment 869 had been discharged after an average duration in hospital of only twenty-five to twenty-six days. In a number of cases, however, although the discharge rapidly subsided, a chronic "gleet" persisted, and it was felt that possibly a better preparation of mercury than the succinimide could be found. On application to the War Office, the assistance of Mr. J. E. Marsh, Lecturer in Chemistry, Oxford University, was enlisted, and it is due to him and to Private Hulls of No. 39 General Hospital Laboratory, that a large number of new compounds of mercury was prepared. Some of these proved too toxic when tested on animals, others were unsuitable for injection on account of their physical properties, and only the benzoate, bi-bromide, camphorimide, phthalimide, argulan, acetanilide and acetamide were tried. None seemed to produce a better effect than the succinimide.

A review of the results after about 10,000 cases had been injected with mercurial compounds showed that no advantage had been gained from their use. It is true that a substantial number of cases had cleared up with extraordinary rapidity, but a large number of those relapsed and a number of others remained in hospital suffering from chronic gleet much longer than the average of this type of case, with the result that the average duration in hospital worked out slightly higher than the average for cases treated on ordinary lines.

In 1917 McDonagh introduced a preparation called "collosol manganese" to be used with or without intramine, according to the case, which he reported later had shortened the stay of gonorrhœa cases in hospital very considerably. Thus his report, dated 3rd July, 1918, on 176 cases treated at the Connaught Hospital showed an average stay in hospital of 15·5 days after commencement of special treatment. Of the 176 cases, 65 had already been in hospital under ordinary treatment for an average of 52·6 days. An improved form of treatment, presumably, the combination of collosol manganese with colloidal palladium or "pallamine" had been tried on 24 cases with an average duration in hospital of 9 days. A subsequent report by Major McGrigor, who had charge of the Venereal Disease Division at the Connaught Hospital, was favourable to this form of treatment, and it was investigated in a number of other military hospitals, being administered according to the following directions by McDonagh :—

" Although for the treatment of acute urethritis a course is mapped out below, each case must be treated individually, great care being exercised in the doses given, the intervals at which they are given, and in cases where a complication is about to supervene, e.g., prostatitis, vesiculitis, etc. Once a complication has set in the treatment is clear.

" *Acute Urethritis.*

1st day.	Collosol manganese (mixture Nos. 1 and 2, solution)	0·5 c.c.	Intramuscularly.
3rd ,,	,, ,, ,, ,, ,,	,,	
5th ,,	,, ,, ,, ,, ,,	,,	
9th ,,	,, ,, ,, ,, ,,	1·0 c.c.	
13th ,,	,, ,, ,, ,, ,,	,,	

" In most cases, at the end of this course, using irrigations twice a day and alkaline mixture internally, the discharge has ceased. When discharge has ceased, the prostate and urethra should be examined, irrigations stopped, heavy work undertaken, and, if all is well two days after, the patient can be discharged. If the discharge continues, it is best to leave the injections off for a week and then start a fresh course. Increasing the doses still further does not at present appear advisable.

" *Acute Prostatitis and Vesiculitis.*

1st day.	Mixture of Nos. 1 and 2 solution	0·5 c.c.
5th ,,	,, ,, ,, ...	0·5 ,,
9th ,,	,, ,, ,, ...	1·0 ,,

" *Chronic Prostatitis and Vesiculitis.*

1st day.	Intramine intramuscularly	2·5 c.c.
5th ,,	Manganese mixture	1·0 ,,
9th ,,	Intramine intramuscularly	2·5 ,,
13th ,,	Manganese mixture	1·0 ,,

" In these cases the prostate and seminal vesicles should be massaged twice a week, the urethra well dilated, 2 c.c. of a 1 : 10 dilution of intramine should be instilled into the urethra also twice a week, while at other times the patient should irrigate twice a day with 1 : 8,000 solution of zinc permanganate."

In No. 51 General Hospital the investigation was carried out by Captains N. Ronan, G. Rawlinson, and the late Captain G. G. Anderson, under the supervision of Colonel O. Richards, consulting surgeon. The number of cases treated by manganese was 102 and the control cases 98. Both series received the same local and general treatment with the exception of the manganese. The test of clinical cure applied to both was freedom from all discharge for seven days and urine clear in two glasses, no folliculitis detected by palpation over a metal sound, and prostate apparently normal. The test of bacteriological cure was absence of gonococci and no undue amount of pus cells or epithelium. The pathologist was not informed of the source of the specimen. The results were as follows :—

	No.	Total No.	Average No. of days
Manganese cases bacteriologically cured ..	66	3,114	46·88
Control ,, ,, ,, ..	64	2,923	45·67
Manganese cases clinically cured	79	2,923	37·00
Control ,, ,, ,, ...	82	3,275	39·94
Manganese cases not cured	23	—	—
Control ,, ,, ...	16	—	—
Manganese cases relapsed	2	—	—
Control ,, ,, ...	5	—	—

Generally the observers remarked that sometimes the injection seemed to be followed by an almost magical disappearance of discharge, but in these cases the urine was clouded with pus. In other cases there appeared to be no effect.

In the military hospitals at Cambridge, Lichfield, Hilsea, Warlingham and New Bridge Street, Manchester, the manganese treatment was investigated on similar lines, with the following results :—

Reporting Hospital.	*Treatment by Irrigation and Intramuscular Injections of Collosol Manganese.*			
	No. of Cases.	Average Duration in Hospital.	Complications while under Treatment.	
			Epididymitis.	Arthritis.
Cambridge.. ..	57	68·9	9	0
Lichfield :				
Major Donald ..	85	57·0	2	0
Lt. Macleod ..	93	55·0	4	1
Hilsea	50	60·82	5	0
Warlingham ..	47	76·0	4	0
Manchester ..	160	52·8	9	0
Totals ..	492	61·75	33 = 6·7 p.c.	1 = 0·2 p.c.

Reporting Hospital.	*Routine Treatment.*			
	No. of Cases.	Average Duration in Hospital.	Complications while under Treatment.	
			Epididymitis.	Arthritis.
Cambridge	57	62·3	0	0
Lichfield :				
Major Donald	252	55·0	7	0
Hilsea	50	54·76	1	2
Warlingham	47	65·0	4	0
Manchester	160	44·5	6	1
Totals	566	56·31	18 = 3·18 p.c.	3 = 0·5 p.c.

Lieut.-Colonel Bolam, Newcastle, reported as follows on a number of cases which were (*a*) first attacks, (*b*) recent infections, and (*c*) previously untreated, half of which received routine treatment and half manganese plus routine treatment.

Observation Period.	No. of Cases.	Suffering from Discharge at end of Period.	Clear of Discharge at end of Period.	In Cases clear of Discharge, average No. of Days clear.
Manganese Series. Weeks.				
5	16	13	3	18·0
5–6	15	11	4	6·25
6–7	11	5	6	13·3
7–8	14	8	6	12·9
8 or more	4	4	0	0·0
Routine Series. Weeks.				
5	16	3	13	17·7
5–6	15	2	13	17·6
6–7	11	1	10	11·9
7–8	14	8	6	12·9
8 or more	4	0	4	19·0

The reports agreed, therefore, in finding no advantage from the use of collosol manganese. An opportunity for instituting a similarly independent test of pallamine did not occur.

With regard to the treatment of gonococcal complications by the injection of intramine, T.A.B. vaccine, and other substances, one of the remedies advocated by McDonagh, namely, intramine, proved distinctly valuable in the metastatic complications of gonorrhœa, when injected intramuscularly in a dose of 2·5 c.c., followed in a few days by a dose of 5 c.c. A similar effect results from the intravenous injection of about 180 millions T.A.B. vaccine and from a variety of substances such as electrargol 2 to 10 c.c., peptone 10 c.c. of 10 per cent. solution given intravenously, and sterile milk 10 c.c. injected intramuscularly. A similar form of treatment has been used with success in a variety of other bacterial infections. The mode of action is unknown, but there can be no doubt as to the value of this form of treatment in gonococcal complications.

At Newcastle, Bolam found that injections of arsenobenzol compounds were most useful in keratodermia blenorrhagica, and this was confirmed later at Rochester Row, where a very severe case of keratodermia was saved from death by intramuscular injections of "914."

Vaccine Treatment.—Vaccines were extensively employed, being prepared in the laboratories of the various hospitals. In No. 9 Stationary Hospital, Dawson and McWhirter prepared a stock vaccine containing 1 part gonococci and 3 parts staphylococci, which appeared to be distinctly valuable.

In 1918, Thomson, working in the laboratory of the Rochester Row military hospital, prepared a vaccine from which he had removed the toxin. It could be given in much larger doses than ordinary emulsion and appeared to give better results. Investigations by Captain D. Lees in four parallel series of cases which were tested for cure by the most stringent tests showed as follows :—

	Duration in Hospital.
(1) Cases untreated with vaccine	58 days.
(2) Cases treated with small doses of ordinary vaccine ..	45 ,,
(3) Cases treated with larger doses of ordinary vaccine ..	42 ,,
(4) Cases treated with very large doses of detoxicated vaccine	35 ,,

Captains Pineo and Baillie tried a new form of vaccine treatment, suggested by Captain L. J. Lickley, R.A.M.C. About 1 c.c. of pus was pipetted from the patient's urethra, and mixed in a test-tube with 10 c.c. saline containing 0·5 per cent. carbolic acid. The pus so obtained and treated from twenty-one acute cases was transferred to a half-litre flask and well shaken. Glacial acetic acid was added to make a 0·5 per cent. solution, and after shaking for one hour an equal amount of carbolized saline was added. After four days the emulsion was estimated to contain 600 million gonococci per cubic centimetre and was diluted with carbolized saline to 24 million per cubic centimetre. The doses administered were successive 6, 12, 18, 24, 36, 60, 72, 90, 120 and 150 million at three-day intervals. The authors claim better results in all stages of gonorrhœa than from any other vaccine and recommend the method on account of its simplicity.

Trial of General without Local Treatment.—In order to test the value of local treatment Major H. C. Donald and Captain A. M. Davidson called for volunteers who were willing to dispense with irrigations and rely only on medicines. Two hundred patients volunteered at once, and the method received a thorough trial. The experiment showed that far better results are obtained from the combination of local with general treatment than from the latter alone. Under purely general treatment it was found at the end of two months that pain and urethral discharge had persisted much longer than under ordinary irrigation treatment, and complications, such as epididymitis and arthritis, were no less, while relapses were more frequent and the duration of stay in hospital was increased by at least fourteen days.

The opportunities of observing the effect of different forms of treatment, which were afforded Lieut.-Colonel Harrison by supervision of venereal disease hospitals containing 10,000 or more beds, enabled him to come to definite conclusions regarding the prevention of epididymitis after admission to hospital. Generally it was found that hospitals provided with a football field, or where physical training was too energetic, had a greater incidence, as also those where irrigation was carried out at too great a pressure, or prostatic massage or instrumentation was instituted too early.

General Conclusions.

In the treatment of syphilis the experience gained during the war showed the limits within which the administration of a given amount of arsenobenzol treatment may be concentrated with reasonable safety. It was not possible to estimate with accuracy the permanence of the results of the routine treatment instituted during the war. Clinical results as regards relapses were good, but the impression gained is that treatment should, in future, be more prolonged than during the war. It was partly for the sake of this that Harrison suggested in 1919 the institution of special treatment centres, which have now been established in close proximity to units, so that treatment can be continued after the patient's discharge from hospital without undue interference with duty.

In gonorrhœa the chief advance was in the treatment by "detoxicated" vaccines and the use of intramine, T.A.B. vaccine, and other products in complications. It must be admitted that the results of treatment of gonorrhœa still leave much to be desired. This is certainly not due to lack of endeavour on the part of medical officers. Harrison testifies to the whole-hearted devotion which the great majority of those concerned in the management of gonorrhœa during the war gave to their task. The tantalizing nature of the problem acted as a stimulus, and a book could be filled with an account of the multitude of methods and remedies tried during the war by the numerous medical officers whose work he had the opportunity of seeing. The problem of syphilis is comparatively simple; gonorrhœa is a totally different matter to the worker who is not content merely to take as his criterion of cure the patient's statement that he is cured. The difference between the patient's standard of cure and that of the conscientious surgeon is very wide but is not apparent to the unskilled onlooker. The duration of stay of gonorrhœa cases in hospital was certainly greater in the war than in the pre-war days, but a real cure was attained in a very much larger percentage of cases, and a strong reason for the longer duration is to be found, too, in the delay in commencing treatment. It has been said of chronic gonorrhœa that its cure takes as many months as it has lasted weeks. It can be said of acute gonorrhœa that its cure takes as many weeks as it has lasted days, with a minimum average of six weeks after the second day. The present-day solution of the gonorrhœa problem lies in treatment at the earliest possible moment. If it were realized by every soldier that gonorrhœa can be aborted with comparative ease when treatment commences on the first day, the special treatment centres now established in the army would be busy and the special hospitals the reverse. Much the same applies in war, and abortive treatment centres in the front areas would be worth battalions of soldiers.

In chancroid and bubo the value of certain definite lines of treatment outlined above was established.

Besides the continuation treatment of syphilis, special treatment centres, established since the armistice, are intended for what might be termed the emergency treatment of venereal disease, that is to say, the diagnosis of syphilis and the first injection of an arsenobenzol compound, and the abortive treatment of gonorrhœa. They can also be utilized for the continuation treatment of gonorrhœa in those cases where the acute symptoms have all subsided and the patient requires only some application or instrumentation at intervals of some days.

The general management of the venereal problem in war appears worthy of consideration, and Harrison advances the suggestion that a venereal policy in war should be worked out in times of peace. Naturally this policy must vary with advances in science, and it must be modified by actual experience in war, but that is a different matter from having to improvise arrangements at a time when those responsible for medical administration are fully occupied with all the other problems incidental to a great war. The obloquy attached to its sufferers seems to affect the arrangements approved for their treatment, and although syphilis is becoming emancipated, the idea that gonorrhœa can be treated in "wash-house" surroundings is difficult to eradicate. Yet the problem is worthy of serious consideration, and the workers in it of careful attention since these diseases were responsible for more than 15,000 soldiers being constantly out of action in England and France during the later stages of the war.

The experience of the war consequently suggests the following principles in determining a venereal diseases policy in war :—

(1) The appointment of an expert in venereal disease on the staff of consultants.

(2) The recognition of special venereal hospitals and provision for them in mobilization stores. Also the provision of the apparatus for emergency treatment of venereal disease in the equipment of each field ambulance, casualty clearing station and hospital train ; in addition, in each casualty clearing station, apparatus for the treatment of chronic gonorrhœa ; and in every unit apparatus for disinfection by skilled orderlies.

(3) The appointment, on mobilization, of officers who are skilled in the treatment of venereal disease, for duty in connection with the prevention and treatment of venereal disease.

(4) The adoption of the principle that temporary officers who show aptitude for venereal work should not be moved without reference to the consultant in venereal disease, just as bacteriologists were not moved in France. In this connection it can be said with definite certainty that it does not pay to change officers frequently and without reference to the number

of skilled officers remaining in the hospital affected. Newcomers who are untrained in the work materially increase war wastage by prolonging the stay of patients in hospital.

(5) Prophylaxis by skilled disinfection, the abortive treatment of gonorrhœa, and the first injection of arsenobenzol in cases of syphilis to be carried out as far forward as possible.

(6) The daily treatment of gonorrhœa to be possible from the moment of reporting sick until the patient reaches the special hospital.

(7) The treatment of chronic gonorrhœa and the continuation treatment of syphilis, both of them weekly matters, to be carried out in casualty clearing stations.

(8) The supervision of all work in connection with venereal diseases in forward areas by specially trained medical officers working under the venereal disease consultant.

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CHAPTER IV.

MEDICAL ASPECTS OF AVIATION AND EXAMINATION OF CANDIDATES.

IN considering the qualities which must be possessed by the military pilot two aspects have to be recognised. First, it has to be asked whether any special attributes are demanded for flying *per se*, and secondly, what are the qualities necessary for combatant service in the air.

The so-called conquest of the air is so modern an achievement, and the apparent advance in aviation was so rapid during and because of the war, that the pilot and his machine are apt to be regarded as super-phenomena, and extraordinary qualities are attributed to the former, chiefly because his activities savour of the mysterious. This view is erroneous and is based on wrong assumptions. It is essentially the view of the onlooker. Seen from the ground the flight of an aeroplane seems uncanny to the onlooker, whose mental horizon is bounded by things terrestrial, and to him the aeroplane high overhead is a frail and vulnerable object, destined possibly, or even probably, to fall suddenly headlong to the earth and be dashed to pieces. The inevitable consequences of a disaster, the idea of insecurity, tend to absorb the thoughts of the inexperienced amateur, with the result that he unwittingly exaggerates the prowess of the individual in the air whose life appears to hang on a thread.

The normal individual once he has mastered the essentials of flight is obsessed by none of these apprehensions. There is no room for such thoughts in his mind, which is occupied by the joy of the thing and the proud knowledge of his own skill. To him the aeroplane is neither frail nor vulnerable ; nor is it some fragile and diaphanous structure high in the sky at the mercy of the forces of nature. On the contrary, in the mind of the pilot he and his machine are the universe, and it is the earth which is small and insignificant. How could his machine be accused of fragility ? The very opposite appears to him to be the case ; not only is he intelligently aware of the skill with which it has been constructed to withstand the strains imposed on it, but still more does the roar of his engine serve continuously to remind him of its enormous power, and he delights to control a mechanism at once so powerful and yet so delicate. The stability of the aeroplane can only be appreciated by the experienced.

It must not be supposed that there are no disturbing influences whatever. On the contrary, an unreliable engine, unsuitable weather, etc., may render the pilot's task the opposite of congenial. At the same time, his mental attitude towards his activities must always differ fundamentally from that of the onlooker.

No attributes are required for flight which are not manifested in the ordinary activities of everyday life and exemplified especially by the playing of games. Successful aviators have been recruited from every walk of life, from various social levels, from different mental and physical types and even at different age-periods. Nor can it be said, from the experience of the war, that any particular trait is essential for success, such as mechanical knowledge, prowess in athletics, physique, imagination, high visual acuity, and so on. Success in aviation —as opposed, for example, to success in rowing, which demands a high physical standard—is open to all. There are, however, certain qualities which come into prominence when reviewing a series of successful aviators ; these are the qualities which are particularly developed by the gradual and subtle processes of character-education, such as independence, initiative, self-reliance, and self-discipline.

On the physical side freedom from organic disease is essential. In addition, the potential aviator must be possessed of a stable nervous system ensuring adequate nervous control, such as is nearly always found associated with the psychological qualities just alluded to. It must be remembered, too, that the war-time pilot is a unit in a disciplined force, constantly at the service of other people, the slave of circumstances rather than a free-lance. Hence the wayward genius with moments of the very highest achievement, interpolated between periods of mediocrity and disinclination, is at a disadvantage compared with his colleagues of more even temperament and less brilliance.

It is not within the scope of medicine to define and isolate in any individual those psychological qualities, the possession of which must inevitably assure success in flying, any more than it is possible to select from a batch of school-boys the future cricketers or mathematicians. The great singer cannot be detected by an examination of his larynx nor the Derby winner by measuring his stride. It is necessary, therefore, to guard against undertaking the impossible, and still more against the illusion that the impossible has been achieved merely because it has been attempted. There has been a tendency to imagine that every pilot is a superman and that the superman can be identified by medical examination, whereas the real facts of the case are that most people can be taught to fly and the medical authorities can do no more than eliminate the unfit. "Unfitness," however, implies a great deal more than a condition of actual disease, and the war has brought home the fact that, apart altogether from gross anatomical changes in the organs, our physical well-being is largely controlled by events taking place in the cerebral cortex. The cortex is constantly being stimulated by every kind of excitation. In the normal state of things many of the stimuli are damped down and but little reaction, mental or physical, supervenes. In states of stress, on the other hand, cortical control is weakened, and the same stimuli, in the absence of higher inhibition, evoke definite reactions. Lack of cortical control, moreover, is evidenced both in the psychical and physical spheres. There is a well-recognized type of person, who owing to defect of the educative processes or to some constitutional weakness, often inherited, is prone to describe a headache as "terrible," a stomach-ache as "excruciating," and a disappointment as "devastating." The same applies in the physical sphere; the individual in whom control has been weakened or never properly developed, screams when frightened, jumps when the door bangs, and faints on parade. The neurasthenic, in whom some toxic or other condition has impaired the controlling influence of the nervous system, demonstrates this escape from control by the symptoms of which complaint is made and by the accompanying physical signs. These symptoms are referable to most of the organs available for clinical examination, and accordingly disturbances of function are found in the sphere of the circulation, of respiration, of excretion and secretion, and of general metabolism. These disturbances being due to lack of central inhibition are characterized by over-action or uncontrolled action, and so it happens that the individual who indulges in psychical superlatives frequently does the same in the region of the physical. This tendency to over-action is most easily studied in the circulatory system, and it is from considerations such as these that a comparatively slow pulse rate, little affected by emotional stress or moderate exercise, has come to be regarded as the most valuable criterion which we possess of what may be called stamina.

For combatant work in the air, as in any other combatant branch of the service, the very highest qualities are demanded. Of all the various factors peculiar to the flying service by far the most important was its individualism. Flying in formation diminished but certainly never abolished this outstanding feature. The flying officer relied essentially on his own skill, his own courage, his own resolution, and his own sense of honour and of duty. He lacked, and most certainly missed, the inspiration born of responsibility to his men and that intimate comradeship in danger which for the infantry officer served as sources of support and encouragement.

One aspect of aviation, namely high altitude flying, is of particular interest to medicine. During the last two years of the war machines attained altitudes at which physical, and more especially mental, efficiency became gravely impaired owing to the effects of "oxygen want." To obviate these effects, appeal was made to the medical service, and it was largely owing to the help thus afforded by medical science that the medical officer came to be associated with the welfare and efficiency of the service in a more intimate manner perhaps than ever before.

Although flying demands no mysterious or hitherto undeveloped qualities, nevertheless it is not free from very considerable risks. The number of fatal accidents which occurred during training in the years of war may be put down roughly at one for every thousand hours of flying. This high proportion was due to the haste in which pilots had necessarily to be trained, the relative instability of the modern fighting machine, the intricate evolutions by which it was necessary to instruct the military pilot to fit him for fighting in the air, and to the particular dangers associated with night-flying. None of these factors come into play in times of peace, but other factors involving definite risks still remain, some belonging to the machine and others to the pilot.

As regards the machine, the danger lies primarily in its speed. The modern aeroplane has a landing speed of not less than 40 miles per hour, and in the event of a forced landing having to be made, whether owing to engine failure, fog, or some other cause, the momentum of the machine coming to earth, very likely on unsuitable ground, must necessarily constitute a definite risk. Another danger, but one which has recently been greatly diminished, is the risk of fire breaking out as the immediate result of a crash.

As regards the pilot, it must be remembered that he is only human and that the air is not the natural habitat of man. Flying for short periods is enjoyable, for longer it becomes monotonous and encourages carelessness, while for longer still it breeds anxiety and a desire to come down to earth. The state of strain induced by anxiety renders the pilot less efficient to discharge what must necessarily be an onerous responsibility.

One other and extremely important factor may be mentioned, namely, meteorological conditions. Flying is not yet independent of the weather, and probably never will be. This is particularly true of long flights. Not only does any condition which lowers visibility increase the immediate risks, but it renders the pilot anxious and deepens his sense of isolation in such a way that the chances of his being guilty of an error of judgment are increased.

In forming an opinion, therefore, as to the kind of human material which is most suitable for employment in the air, while recognizing that the art of flying can be attained by the ordinary individual, it must not be forgotten that the aviator will be exposed to very considerable risks and must consequently be of the type that can face them with equanimity.

EXAMINATION OF CANDIDATES FOR MILITARY AVIATION.

The necessity of submitting candidates for the air service to a medical examination more detailed and of wider scope than that employed in deciding a man's fitness for general duty in other branches of military service might be presupposed on purely theoretical grounds. The nature of the aviator's duties in guiding and controlling a machine moving at considerably higher speeds than those hitherto experienced, the performance of movements exposing him to the effects of rapid rotation with possible loss of control, the accurate judgment of distance involved in landing, the conditions of temperature, atmospheric and oxygen pressure under which his work has to be carried out, the nervous stress imposed in training and in flying on active service, frequently at high altitudes, are all points which suggest the necessity for a high degree of physical efficiency and acuteness of the special senses.

The cost also of training and the loss resulting from sudden physical failure in the air or from gradual breakdown in the course of his duties render it highly desirable that the would-be pilot who on medical grounds is unfitted for aviation should be excluded at the outset.

As early as 1916 medical officers with flying squadrons and the authorities at headquarters had collected considerable evidence which proved that the opinion formed on theoretical grounds was supported by actual experience of the results of training and flying service overseas. The medical officer was constantly seeing pilots who were breaking down or had actually broken down from causes which obviously should have excluded them from the air force.

In addition to visual defects, inflammation of the middle ear and conditions resulting in Eustachian obstruction, numerous instances of gross nervous instability were observed amongst unfit flying officers, who could never have been accepted for the service had details of their past histories been elicited at a medical examination.

To obviate as far as possible this condition of affairs, in October 1916 a special medical board was instituted at headquarters for the purpose of examining candidates and dealing with officers and pupils who had broken down. The board worked in conjunction with the Air Board Medical Research Committee, the functions of which were the investigation of various medical problems connected with aviation, and the laying down of standards to be employed in the selection of candidates.

For various reasons during the early months of the board's existence only about 40 per cent. of applicants for commissions as flying officers were submitted to the special medical examination, but an analysis of the results showed that the board was able to reduce the percentage of pupils breaking down during training from physical causes by 50 per cent.

The work increased steadily and by November 1918, 60,000 candidates had been examined by the Board.

The centralization of the work of medical selection under the conditions existing during the war had the advantage of combining ease of administration with economy of medical personnel. A greater degree of uniformity in the methods of examination and in the final assessment of candidates was also secured.

Owing to the very large numbers which the medical board was called upon to examine and to the smallness of the medical staff available, it was necessary that the scheme of examination should be drawn up on the simplest lines compatible with the special object in view. Elaborate methods of examination, however valuable, had perforce to be excluded.

Candidates after the preparation of their examination papers were submitted to :—

I. A surgical examination, comprising observations as to any existing surgical abnormality, congenital or the result of injury or disease, measurement of height and weight, and tests of acuity of vision and colour vision.

II. A medical examination, including enquiries as to previous occupation, proficiency in sports, family and personal medical history, an investigation of the various systems and the performance of the " breath-holding " and " pulse rate after exertion " tests.

III. An examination of the ears, nose, throat and buccal cavity, including tests of hearing and patency of the Eustachian tubes, and the following special tests :—
  (i) Self-balancing with eyes closed.
  (ii) Balancing rod on board.
  (iii) Barany's tests (applied only in certain cases).

IV. An assessment in which, after such further examination as appeared necessary, a decision was formed as to the candidate's fitness for flying.

In addition, candidates whose vision was worse than 6/9, 6/12, or whose colour perception was defective, were submitted to a more detailed ophthalmic examination. Candidates also who had failed to hold the breath for fifty seconds underwent further tests for respiratory capacity.

The examination, as described, of 200 candidates per day required a staff of sixteen medical officers, consisting of two surgical, seven medical, and three aural examiners, an ophthalmic surgeon and three assessors.

The significance of the various points elicited by enquiry, the value to be attached to signs or to responses to tests, and the general principles upon which a decision as to a candidate's fitness was based are briefly outlined below. They are the results of a comparative study of the physical characteristics of successful pilots and unsuccessful pilots and pupils, and of the analysis of the records of the Aviation Candidates Medical Board.

Age.—The age limits fixed during the war for candidates for the flying service were 17½ and 30 years. An analysis of a series of accepted candidates whose subsequent histories were traced as regards success and failure in training, appears to show that the boys of 17½ to 19½ and the men of 26½ to 30 were less satisfactory pupils than those of 19½ to 26½. If, however, the causes of failure in the age groups are examined, it is seen that temperamental unfitness and failure in examinations predominate in the group 17½ to 19½ and temperamental unfitness and fatal crash in the group 26½ to 30.

The youngest age group would naturally contain a higher proportion of pupils of inferior intellectual attainments and of unsuitable temperament as yet uneliminated by any process of natural selection. Putting failures from these causes aside, the remainder of these boys made good in training as frequently as the men of 19½ to 26½.

Taking all points into consideration, it is probably correct to say that under the conditions existing during the war, namely, recruiting from all classes and occupations, and with the standards of theoretical knowledge required, the most suitable and economical age period extended from 19½ to 26½ with an optimum period of 20½ to 24½.

Occupation.—As an indication of mental and physical capacity and to some extent of temperamental suitability, occupation is a point of some prognostic importance in the selection of candidates. Occupations associated with fairly high intellectual attainments and affording opportunities for outdoor sports or pursuits in the open air under healthy conditions showed a high percentage of successes in training. The student, the schoolboy, though in the youngest group, and the farmer form a class which was more generally successful than those drawn from the office, the workshop or indoor trades.

Temperament.—No attempt was made to determine by means of a psychological examination the temperamental suitability of candidates. The examiners, however, in most cases were able to gain an insight into the candidate's general " make up " by interrogation as to his motive for joining the air service, his keenness for certain sports such as Rugby football and boxing, and his previous service in the war. Service in the front line, if unattended by signs of nervous stress, was generally regarded as indicative of a temperament fitted for air work, and men with experience of such conditions were found to include a larger number of subsequent successes than those who had not been subjected to this process of natural selection.

Further evidence was also obtained from observation of the candidate's demeanour in the examination room and from the degree of resolution he displayed in the performance of the " respiratory tests."

Although a decision as to general fitness was seldom based solely upon a review of temperamental characteristics, yet in cases which were physically on the border-line such considerations frequently turned the scale towards acceptance or rejection.

Vision.—The degree of visual acuity requisite for the pilot has been the subject of much discussion and is not yet definitely settled. On theoretical grounds no doubt normal vision in each eye appears desirable, but during the war, when the supply of men was limited and the demand for pilots great, this standard, which would have resulted in the rejection of 25 per cent. of otherwise fit candidates, could not be maintained, and defects as high as 6/12 and 6/18 were allowed, provided that vision with glasses could be brought up to 6/6 and 6/9.

The view that this lowering of the visual standard was justifiable is supported by such figures as are available, in which the number of defectives among accepted candidates is found to be only one-sixth greater than that among pilots who had flown for 700 hours or who had won distinctions for prowess in the air. Such slightly excessive falling out as did occur among visual defectives appears to have taken place to a great extent among those whose vision was worse than 6/9 in each eye.

The degree of importance to be attached to ocular muscle balance was not at first fully realized, and no routine observations for heterophoria were included in the examination until late in 1918.

Colour vision was tested by means of the Edridge green lamp. Inability to distinguish between red and green lights is obviously a source of danger in night-flying, and dichromics were accepted only for subsequent employment as delivery pilots.

There was no evidence to show that red-green blindness diminished the pilot's powers of discrimination in the choice of suitable landing grounds.

Ears and Upper Respiratory Passages.—The examination was conducted with a view to ensuring adequate acuity of hearing —ability to hear a forced whisper at 20 ft. with each ear, the other being occluded—and freedom from any abnormal or unhealthy condition of the ears themselves or of the upper respiratory passages which might tend to interfere with the auditory sense or the vestibular mechanism.

Sepsis, whether of teeth, gums, tonsils, or accessory sinuses, had to be completely eradicated by appropriate measures. Free nasal respiration was required and any obstructive condition, such as deflected septum, had to be removed. Pronounced mouth breathing which had become habitual, even if the cause no longer existed, was still regarded as a ground for rejection. It had to be remembered that conditions of but slight importance on the ground might in flying become aggravated and assume disabling proportions; for this reason candidates suffering from small masses of adenoids resulting in frequent colds or deafness, or from unhealthy conditions affecting the Eustachian tubes and liable to give rise to giddiness in the air owing to inequalities of pressure in the outer and middle ears, or from septic conditions of the gums and tonsils, however slight, were, if otherwise fit, deferred for treatment.

Vestibular Mechanism.—With regard to the part played by the semi-circular canal system in the maintenance of equilibrium in the air, the view put forward in America that the pilot relies pre-eminently on his "ear balance sense" has not been adopted by the British authorities.

It was considered advisable in a series of cases, however, to determine the integrity of this system by means of the methods introduced by Barany. At the same time it was realized that the excitation involved by rotation in the chair was grossly excessive, and that accordingly it was not possible to draw deductions as to the "sensitiveness" of the labyrinthine apparatus from the intensity of the reactions invoked. A reaction, however, characterized by nausea, vomiting, pallor, etc., or a definite history of previous train or swing sickness, was found so frequently associated with inability to qualify, or with early breakdown, that it was held to be a ground for rejection.

Skeletal and Muscular Systems.—Defects of these systems were considered from the points of view of any congenital or acquired condition, of which they might be evidence, and from the incapacitating effect they exerted upon muscular power, freedom of movement, and manipulative ability. In estimating the degree of disablement present, the character of the work which the pilot was called upon to perform and the conditions as regards temperature and fatigue to which he would be exposed, had to be borne in mind. Any defect liable to affect his control over rudder-bar and joy-stick, or to interfere with dexterity in the manipulation of switches or in the working of the gun, was regarded as a disqualification.

Large scars or defective circulation in a limb, the result of injury to vessels, are frequently the cause of disabling cramp under conditions of extreme cold and exposure, and their presence therefore necessitated careful consideration.

Respiratory System.—A history of recurring or chronic affections of the lungs if of recent date was considered a ground for rejection. Candidates who had suffered from pleurisy, in view of its frequently tuberculous origin, were regarded with grave suspicion. Definite signs of tuberculous disease, arrested or active, chronic bronchitis, emphysema or asthma disqualified.

Adequate range of movement of the chest as a whole was demanded. Conclusions drawn from the maximal and minimal chest measurements at the nipple-line did not prove entirely satisfactory, and it is considered that more valuable evidence in this respect is derived from the data provided by a comparison of vital capacity with stem length and body weight, as suggested by Professor Dreyer.

The so-called "respiratory tests" devised by Wing-Commander M. Flack and described by him in the following chapter, if carried out according to instructions and with regard to possible sources of fallacy, such as temporary indisposition, have been found from a consideration of the previous and after histories of large numbers of candidates to give reliable evidence as to general functional efficiency and adequacy of the respiratory system, and to afford valuable assistance to the assessor in making his final decision upon the entire medical examination.

Digestive and Urinary Systems.—Sound digestive and excretory organs are necessary if the nervous and cardio-vascular systems are to be maintained at a high level of efficiency.

The interaction of poor digestion and nervous strain forms a vicious circle in the presence of which a pilot cannot long fly with success. A history of frequent gastric disturbances was regarded as evidence of possible serious disability. Any evidence of impairment of renal function or of glycosuria was considered a ground for rejection.

Cardio-vascular System.—The maintenance of an adequate circulation under adverse conditions of strain and low oxygen pressure is obviously of vital importance to the pilot.

Enquiries were made as to a previous history of rheumatism, rheumatic fever, chorea, diphtheria or any infectious condition liable to affect the heart muscle. A history of breathlessness, precordial pain, exhaustion, fainting or giddiness associated with change of posture or effort was considered suggestive of a defective circulatory mechanism. Valvular or myocardial disease definitely disqualified. A systolic murmur in the absence of a rheumatic history or of an accentuated pulmonary second sound or of enlargement of the heart was disregarded.

Arrhythmia of the Heart's Action.—At the age at which candidates presented themselves for examination a sinus arrhythmia was frequently present and was regarded as of normal occurrence. The presence of isolated extrasystoles, which disappeared on exertion, was not viewed unfavourably unless associated with signs of nervous instability or a sensation on the part of the candidate as of the heart stopping or turning over.

Very infrequently runs of premature contractions were observed suggestive of abnormal impulse formation and were regarded as a disqualification.

The graver forms of arrhythmia were rarely met with ; no case of auricular fibrillation and only one of auricular flutter were noted.

Rapid Action of Heart.—A pulse rate of 108 to 132 was not infrequent and as a rule was proved to be due to the nervous excitement of the examination ; this, though not regarded as a serious sign, was not looked upon with favour.

A few simple observations on the tachycardia, such as noting its association with rapid respiration in the absence of more than one degree of pyrexia, or the occurrence of slowing after a few deep breaths in the recumbent position, or of marked reduction in the rate during expiration, generally sufficed to render the cause of the condition clear. A rapid rate, persistent and unaffected in the ways described, required further investigation as to the possibility of its being due to some toxic or inflammatory condition of the heart muscle.

Slow Action of the Heart.—Bradycardia of extreme degree was never met with, and the slow, well-sustained pulse of 60 was looked upon as a favourable sign.

Functional Efficiency of the Cardio-vascular Apparatus.—So far attention has been directed to the recognition and elimination of cases of organic disease or incapacitating abnormalities of the heart's action. The question—and this was one which in the actual selection of suitable candidates was of the greatest importance—as to the functional efficiency of the circulatory system as a whole had to be considered.

Evidence of a practical nature helpful in forming a decision on this point might be forthcoming from a consideration of the candidate's previous history as regards the symptoms pointing to cardio-vascular inefficiency already mentioned, or from information elicited as to his capacity to undertake labour of an arduous character or to take part in strenuous sports.

Long-distance swimming, Rugby football, boxing, and cross-country running are all sports success in which is an indication of functional cardio-vascular efficiency.

In the medical examination of the candidate good arterial tone as shown by a sustained radial pulse was always insisted upon. A correct estimation of this by palpation of the radial artery is a matter which needs considerable experience on the part of the examining officer, but even so mistakes are unavoidable. The only scientific and reliable method of estimating systolic and diastolic pressure is by the use of the sphygmomanometer.

Three types of pulse are commonly met with : —

(i) The pulse with well-maintained diastolic pressure and average pulse pressure.
(ii) The pulse with high systolic and well-maintained diastolic pressure.
(iii) The low pressure collapsing pulse with average systolic and low diastolic pressure.

The first of these is satisfactory ; the second is frequently found in the highly strung, excitable individual but is not by itself a cause for rejection ; the third is definitely indicative of defective nervous control, and other evidence pointing in the same direction is generally obtainable.

There is another type of pulse which though infrequently observed among the general run of candidates is indicative of a high degree of efficiency and is associated with stamina and general stability of the nervous system. This is the slow pulse of 60 to 72 with a well-maintained diastolic pressure and small pulse pressure of about 30 ; the impression gained by feeling this pulse is that of a smoothly acting cardio-vascular machine working efficiently, with no waste of energy and considerable reserve of power. It constitutes perhaps the most valuable single clinical sign of stamina and physical efficiency.

Further aids to a correct assessment of the cardio-vascular system were derived from a consideration of muscular tone, particularly as exhibited by the abdominal wall and stomach. A soft, flabby, toneless condition of the former or the presence of " splashing " in the latter more than three hours after the ingestion of food or liquid, is frequently associated with poor arterial tone and a tendency to splanchnic flooding, which with the candidate in the horizontal position may be shown by considerable distension of the external jugular veins, further increased by abdominal pressure.

Certain tests, such as that of the response of the pulse to exertion and of its behaviour during the supporting by the breath of a column of 40 mm. of mercury, also give valuable indications and are described in Chapter V.

In forming an opinion as to the efficiency of the cardiovascular system, it had always to be recognized that emotional effects are frequently produced by subjecting a candidate to the ordeal of physical examination, and these had to be interpreted according to the judgment of the examiner.

Nervous System.—Gross organic disease of the central nervous system was practically non-existent at the age at which candidates presented themselves, but a diagnosis of such a nature necessarily resulted in rejection, as did also a history of epilepsy whether of the major or minor form. The pareses due to old anterior poliomyelitis were judged on their merits according to the muscular power remaining. A history of concussion, if not of too recent a date and if unassociated with signs of nervous sequelæ, did not disqualify, and in fact was considered a favourable point as possibly showing a suitable temperament and a nervous system fitted to withstand the physical shocks incidental to flying service. Recent severe concussion, however, was regarded with grave suspicion; candidates accepted with such a history in the great majority of cases did badly.

The all-important question upon which a decision had to be formed was as to the degree of nervous control or stability possessed by the candidate. In forming such an estimate information regarding the candidate's family history, though most important, was usually difficult to obtain; evidence was more frequently forthcoming from enquiries directed to the personal medical history as regards abnormal nervous manifestations during childhood, such as night terrors and somnambulism, or conditions occurring later and associated with instability of the nervous system, such as hay fever or migraine. A history of nervous breakdown, the result of mental or physical strain, was viewed unfavourably.

It is well known that mental (cortical) disturbances are readily reflected in the circulatory system. Hence an examination of the circulation on the lines already described afforded valuable evidence as to the stability or otherwise of the central nervous system. Similarly, further evidence in this respect was to be obtained from an examination of the neuro-muscular system. The observations and tests to which, as the result of experience, most importance was attached were the candidate's demeanour in the examination room, the presence of restless movements, habit spasms or stammering, considerable tremor of fingers, eyelids, or tongue, and unusual inability to stand on one foot with the eyes closed.

Tremor and poor capacity to balance on one foot with the eyes closed were frequently observed by the invaliding medical board among pilots who had broken down. Investigations also showed that candidates accepted in the early days of the board's existence, though presenting these conditions, included such an abnormally high percentage of subsequent failures during instruction that the presence of one of them, or still more of the two combined, came to be regarded as evidence weighing heavily in the balance against acceptance.

A brisk or exaggerated tendon reflex as a single sign has not been found to be unduly associated with failure, but combined with considerable tremor and poor self-balancing, unless due to some temporary indisposition, formed a group of signs of sufficiently grave prognostic importance as to justify the rejection of the candidate exhibiting them.

Assessment.—The duty of forming a final decision as to the candidate's fitness for air work rested with an assessing medical officer who had had experience of the routine examination. His decision was based upon a review of all the facts and observations recorded by the examiners, checked and supplemented by a short examination on his part and by further investigation of such points as appeared doubtful.

Apart from the elimination of candidates who failed to satisfy the requirements in respect of the special senses of sight and hearing or showed signs of organic disease of a gross or potentially disabling nature, the assessor's main duty was to ensure that the accepted candidate was possessed of a degree of stamina and nervous stability adequate to withstand the stress of training and of subsequent service in the air.

In forming an opinion on these points, evidence as to the soundness of the stock from which the candidate came, the illnesses from which he had suffered, the sports at which he was proficient or excelled, the stresses to which he had been exposed and the manner in which they had been borne, was of prognostic importance. Reliable impressions were also formed in many cases in the course of ordinary clinical examination, but additional aid in arriving at a decision was afforded by a consideration of the candidate's responses to the various tests of the cardio-vascular, respiratory and neuro-muscular systems.

CHAPTER V.

TESTS FOR FLYING EFFICIENCY AND FLYING STRAIN.

EXPERIENCE has shown that various attributes were necessary in an individual who was to train into a successful pilot. In the first place, he had to be possessed of the ability to acquire the art of straightforward flying. Having achieved this, it was necessary that he should be able to learn to perform " aerial acrobatics " of a complex and nerve-trying nature ; and these demanded considerable manipulative skill in addition to nervous stability.

Secondly, he had to be capable of withstanding the strain of flights at high altitudes as well as of flights of long duration. These imposed considerable strain upon the bodily systems, particularly upon the respiratory, circulatory and nervous systems.

Thirdly, and in many ways most important of all, he had to possess the correct mental aptitude not only for flying but also for combatant service in the air.

Experience during the war showed that quite a considerable proportion of candidates admitted as pupils failed to qualify as pilots, being classed by the officers training them as either " temperamentally unfit for flying " or deficient in mechanical aptitude, or " heavy hand, unlikely to learn to fly."

In the earlier stages of the war, also, a number of pupils were admitted who, at the very beginning of their career, found that they were unable to withstand the effects of altitude (" oxygen want ") and for this reason had to cease training as pilots.

After qualification as pilot, war flying imposed a great strain upon the aviator, so that in consequence breakdown was common. In addition to frequent psychical disturbances, the patients were found to suffer from gradual loss of power to fly high, associated in varying degrees with particular symptoms of cardiac and nervous derangement, such as quickened pulse rate, increased pulse pressure, "splashing" stomach, tremor of fingers and eyelids, poor power of balance.

It was therefore a point of the greatest medical importance that some simple tests should be devised which would serve (*a*) to aid in the efficient selection of suitable candidates for flying service and (*b*) to demonstrate in serving officers the need for rest, or at least, for lessened work at a stage when the pilot himself frequently did not feel justified in complaining to his medical officer.

The tests which came into general use are given below. It should be remembered, however, that many of these tests were devised to serve as adjuncts to the general clinical examination. It was found that some purely temporary cause might be the reason of failure in some of the tests, and on this account instructions were given that attention should be directed to the subject's performance as a whole rather than to failure in any one particular test.

Tests for Visual Aptitude.

In acquiring the mechanics of flight good visual acuity is of great importance. It is generally held that such acuity should be normal as tested by Snellen's type. During the war, however, the standard of visual acuity was reduced owing to the needs of the service, but after the armistice it was again raised to normal.

With the object of ascertaining the importance of visual acuity in the flying officer, Lieut.-Colonel Bowdler analysed the records of the Aviation Candidates Medical Board. The total number of records examined was divided into five groups according to the stages reached by the individuals in their flying careers, and the frequency of occurrence and degree of defects in the various groups ascertained for comparison. No individual with worse vision than 6/12 or 6/18 was included.

Group I.—3,000 candidates examined and accepted for training as pilots.

Group II.—123 pupils training as pilots who failed to qualify—failure occurring during instruction in flying.

Group III.—633 pupils who were successful in gaining their wings.

Group IV.—200 pilots who have been awarded the Distinguished Flying Cross, and in some cases the Bar. Though the average number of hours flown by this group is not known, it is probably considerable, but less than that of Group V.

Group V.—363 pilots who have been medically examined by the Board when applying for a civilian flying licence. This group consists almost entirely of experienced pilots with an average of 800 hours flying per man. It includes no fewer than 110 pilots, each with 1,000 or more hours to his credit, many of whom were flying before the outbreak of war.

Not included in this group were 20 pilots, examined for licence (average hours flying 1,000), who were found to possess worse defects than 6/12, 6/18.

In considering the percentages under the various grades of defect within the standard allowed, it was thought advisable in view of the small numbers with the higher defects to group the defectives in two classes for purposes of comparison :—

(1) Those with small defects, *i.e.*, $\frac{6/6}{6/9}$ $\frac{6/6}{6/12}$ $\frac{6/6}{6/18}$ $\frac{6/9}{6/9}$

(2) Those with comparatively large defects, *i.e.*,
$\frac{6/9}{6/12}$ $\frac{6/9}{6/18}$ $\frac{6/12}{6/12}$ $\frac{6/12}{6/18}$

It is to be noted that those with normal vision in the better eye are placed among the class of small defects, as vision with both eyes together would be equivalent to 6/6.

The number of defectives in the various groups classed in this way are shown as percentages of the totals examined in the following table :—

TABLE I.

	No.	Per cent. visual defects.	Per cent. small defects.	Per cent. large defects.
Group I. Accepted candidates	3,000	24·4	19·2	5·2
Group II. Pilot pupils failing	123	18·7	13·9	4·8
Group III. Pilot pupils qualifying	633	18·6	12·98	5·7
Group IV. Pilots with distinctions ..	200	20·5	18·5	2·0
Group V. Civilian pilots ..	363	20·1	17·9	2·12

From the above table it will be seen that among the successes and failures of the pilot pupil groups there is little or no variation in the frequency of defects of visual acuity within the limits laid down.

Comparing, however, the groups of pilots of long experience and distinction with the accepted candidates, there is a diminution of 4 per cent. in the frequency of visual defects among the former ; three-quarters of this diminution occurring among those with comparatively large, and one-quarter among those with comparatively small defects. This is suggestive of some falling out from flying, on account of deficient vision, of men with the comparatively large defects.

Of 383 experienced airmen, 93 pilots, who in the aggregate had flown for 75,000 hours, failed to reach the standard of normal vision in each eye. Of these, 65 had small, and 8 large defects within the specified limits, while 20 had defects ranging from 6/12, 6/18 to as high as 6/60 in each eye.

It will be seen on the whole, therefore, that for military service the available evidence is in favour of normal vision in pilots; small defects only being in any way admissible, if prolonged efficient and distinguished service is to be rendered by the candidate.

Besides good visual acuity, it was found, as the result of the investigations of Wing-Commander E. C. Clements, that good ocular muscle balance with good visual fusion was particularly necessary if the subject were to learn to land his machine properly.

Experience has also shown that, from one cause or another, ocular muscle defects may appear after admission either in cadets during training or in officers after considerable periods of service. These defects create difficulty and even inability to estimate the distance the subject is above the ground, causing "flattening out" too soon or too late and consequent bad landings.

Lack of proper ocular muscle balance (heterophoria) may be due to either weakness or over-action of certain of these muscles. The following simple tests are now employed at the aviation candidates' medical board and are also circulated to medical officers for use at aerodromes.

Tests for Convergence Power.—Hold a pencil in front of the patient about 12 in. from his eyes, with the point on a level with the root of the nose; telling him to look at the point, steadily move it towards him, watching what happens to his eyes as you do so.

(1) Both eyes may converge, fixing the pencil until it gets an inch or two from the root of the nose; *i.e.*, no lack of convergence.

(2) (*a*) One or other eye may cease to move inwards, and may even wander outwards—or

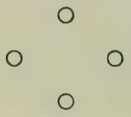
(*b*) Both eyes may fail to keep up fixation. The patient may even resist by throwing back his head, and complain either that "it hurts him to follow the pencil," or that he "sees double" when the pencil is nearer his eyes than 10 in. In any such cases convergence is defective.

Cover Test for Muscular Defect.—Ask the patient to "fix" a pencil held as before. Cover one eye for a few seconds, and then uncover; watch whether the eye moves on uncovering. Repeat the test for the other eye. A normally balanced pair of eyes will remain fixed on the pencil whether one eye is covered or not, whereas movement, inwards or outwards, on uncovering shows lack of balance. Slow recovery from such wandering indicates greater defect than fast recovery.

The following tests were found by Wing-Commander Clements to be best adapted for the full elucidation of such defects :—

The Red-green Test.—The apparatus consists of a box and a pair of spectacles.

The box measures 9 × 9 × 6 in., and is made of wood painted dead black, and contains a 16-c.p. electric lamp. In one side of the box is a vertical slot, 5 × ½ in. ; in another side is a similar sized horizontal slot. These slots are glazed for half their length with red glass and for the other half with green glass. A third side is pierced by four circular holes, 1½ in. in diameter, arranged at the corners of a square standing on one corner, thus :—



The upper hole is glazed with white opal glass, the lower with red, and the two horizontal with green. All slots and holes are further backed by white opal glass to diffuse the light.

The spectacles are reversible, and glazed red for one eye and green for the other. Care is taken that the red and green glass used in both the box and the spectacles is cut from the same two sheets of coloured glass, which should be of sufficient density to neutralize each other.

This test is based on the fact that a pure-neutral red glass of suitable density will not allow neutral green light to pass through it, and *vice versa.*

Thus, a normal person, viewing two adjacent sources of light, one of which is red, and the other green, through a pair of spectacles having a red glass in the right eye, and a green glass in the left, will only see the red light with the right eye and the green with the left. Any tendency to variation in alignment of the visual axes (normally balanced by sub-conscious muscular adjustment) will therefore become apparent by a variation in position of the two images.

Method of applying the Test.—The subject, wearing the reversible frame, is seated 20 ft. away from the box, and can be shown any side of it. If, for example, he is shown the vertical slot, he may say that he sees :—

(i) Two lights :—
  (*a*) in their proper position, *i.e.*, perfect alignment of visual axes and correct ocular muscle balance ;
  (*b*) with definite displacement up or down and/or right or left, *i.e.*, *hyper-* or *hypo-* and/or *eso-* or *exo-phoria* ;
  (*c*) one, or both, of which wanders from its original position and back again, *i.e.*, a tendency to *heterophoria*, but with some or full power of correction.

(ii) At first two lights, then an occasional disappearance of one of them, either the same one all the time, or the two alternately, *i.e.*, mastery of one eye, either continuous or alternating, with neglect of the other.

(iii) Either colour singly, but never the two together :—
  (*a*) red and green alternately, *i.e.*, alternate fixation with suppression of the other image.

It may happen that the two colours may be superimposed and fused into one image. Reversal of the frame will obviate this difficulty, as the colours will then be widely separated.

The nature and amount of displacement will indicate the quality and quantity of the phoria thus revealed.

Bishop Harman Diaphragm Test.—The essential principle of the test is the estimation of the relative capacity of individual subjects to maintain an even ocular muscle balance, and therefore binocular single vision, under increasing disability by progressively diminishing the overlap of the binocular field of view, and, further, it aims at so standardizing the conditions as to produce an absolute estimate of this capacity.

The instrument consists of a rod, one end of which is free and bears a T-piece, shaped to fit the upper lip, to which it may be pressed by means of a handle fixed below the rod. At the other end, 44 cm. away, is a vertical card-holder in the plane at right angles to the rod. Between these, 11 cm. from, and parallel to the card-holder, is a diaphragm in which a rectangular aperture is cut, through which the subject views the test card. The aperture is capable of being widened or narrowed at will by means of two shutters, one on either side of the opening, actuated by a right and left-handed screw, which is rotated by means of a milled head. Movement of the shutter operates a pointer which registers the degree of movement on a quadrant scale. This scale is adjustable to the widely varying pupillary distances of individual subjects.

With wide-open diaphragm, all the figures on the test card can be seen by both eyes. As the shutters are gradually approximated, less and less of the card is seen by both eyes together, until there is eventually only half the card visible to each eye separately, and no overlap of the fields of view. The scales are so calibrated that zero represents an overlap of 3 mm., and every unit above zero represents 1 mm. more of overlap.

If the quadrant scale be adjusted for the inter-pupillary distances of individual subjects looking at a point 44 cm. from their eyes, and readings taken when binocular single vision is just breaking down, standardized reports can be prepared as to individual capacity to maintain binocular single vision, *i.e.*, an estimate of relative ocular muscle balance, and, further, such readings, taken for the same subject at intervals, can be charted and his variations compared.

A considerable amount of valuable information can be obtained by asking the subject to say precisely what has happened when he indicates that a change has taken place ; for instance, he may state that :—

(1) The test card is being cropped from one or other side, *i.e.*, the figures at either end begin to disappear, indicating *suppression* of one or other image ;

(2) The middle figures tend to crowd together and mix up, indicating *esophoria* ;

(3) The figures divide and the centre figure is duplicated, and even a black bar appears between them, indicating *exophoria ;*

(4) Some of the figures take a higher or lower level, indicating *hypophoria* or *hyperphoria.*

(5) Finally, a black bar appears, obliterating the middle figure, but the rest remain in their proper relative positions, indicating that the overlap has been entirely cut down, and that there is a negative gap, which is represented by blackness ; in such a case, the reading will be below zero, and indicates a *perfect control of balance.*

The Orthotelemeter.—This instrument is based on the principle used many years ago for testing monocular and binocular vision at a distance of not more than 2 metres. Of recent years it is believed that a form of the test has been employed by the German authorities in testing the vision of officers, but details are not available. Recently in this country, Professor C. E. Spearman has used the principle for testing stereoscopic vision.

Its present use is in some ways a reversal of its previous application, as it is now used for Royal Air Force work at a distance of 6 metres, for estimating true judgment of distance.

The apparatus, as designed and constructed in the laboratory of the Medical Research Department, Royal Air Force, consists of a toy railway bogie running on its own track of about a metre in length. The track is fixed to the top of a small table, at the far end of which is a glass screen forming the front side of a box in which is a 25-c.p. electric lamp. At the near end of the table is a larger screen of three-ply wood, painted dead-black on both sides, in which is a horizontal slit. A cord passes through a hole at the bottom of the wooden screen to the near end of the bogie, and a similar cord passes from the far end of the bogie to the far end of the track, where it passes over a small pulley, through a hole in the table, to a weight hanging beneath. The near cord should be about 8 metres long, so as to allow of its being operated by the subject of the test, who sits on a chair 6 metres away from the table. It is desirable to have a metal hook and a series of knotted loops 2 or 3 metres from the far end of this cord, so that the cord may be shortened or lengthened at the will of the examiner in order to cause the subject to grasp, at intervals, a different part of the cord. Thus, if he makes what he considers a successful attempt, he may not rely on his memory of the position of his arm when making that attempt to enable him the more readily to repeat his believed success.

Half-way down the track, and 5 cm. on either side of its middle line, are two thin needles (the finest knitting needles serve) secured vertically to the table-top and in a plane at right angles to that of the track. The bogie carries a similar needle vertically on its centre. These needles should not be more than 1 mm. in thickness, and should be about 18 cm. long ; they should all be coated dead-black, but this must not perceptibly increase their thickness.

A millimetre scale, marked zero in the middle, and extending to 20 cm. at each end, is attached to the table-top close and parallel to the track, so that at zero the needle on the bogie is exactly in a line with the two stationary needles, the bogie carrying a pointer almost touching the scale to facilitate this measurement.

The subject is seated 6 metres away from the apparatus to eliminate his power of judging distance by accommodation. The loops in the cord have already been explained. The wooden screen with the horizontal slit allows vision of only about 3 cm. of the middle of each needle, and cuts out the tops of the needles and the track and bogie. The thinness of the needles as nearly as possible eliminates the variations in the apparent size within reasonable limits of movement. The totally enclosed lamp behind the glass screen, while evenly and adequately illuminating the background of the needles, prevents any stray light from illuminating extraneous objects. The needles are blackened to prevent their reflecting accidental light from their sides, and thus giving a guide to their position by variations in light and shade.

Method of applying the Test.—The apparatus is set up in a room which can be almost completely darkened. The subject is first shown the apparatus, which is explained to him. He is then seated in the chair and the near end of the cord is put into his hand. The room is then darkened, and the dark screen illuminated by its own lamp. After a preliminary view through the aperture in the wooden screen, where he sees the silhouettes of the middle portions of the three needles, *and nothing else*, he is asked to operate the cord so as to get the middle needle in a line with the two outer needles, *i.e.*, at the same distance from him. He is told to say " Right," when he is satisfied with the position of the middle needle ; no comment is made on his attempt, but the exact reading is recorded. Ten readings in all are taken, and the result is preferably plotted graphically on either side of a zero line.

Results so far show a definite tendency on the part of myopics, esophorics, and pilots who are apt to fly into the ground on landing, to place the middle needle beyond the outer needles, *i.e.*, farther from their eyes and nearer to the illuminated glass screen, and on the part of hypermetropics, exophorics, and pilots who " land too soon," to do the reverse.

When, from the results of the above tests, there is reason to believe that there is a tendency to suppression, either constant, alternating or occasional, the use of " G " series of Wells' Stereoscopic Charts* in a stereoscope gives a confirmation and also an estimate of amount by recording the card, which first shows a failure to appreciate the marks or signs necessary to be seen by one or other eye.

Wing-Commander Clements found that many of the defects shown by these tests were amenable to treatment by suitable eye exercises with Worth's amblyoscope and Wells' charts. During the period August 1917 to July 1918 he saw and treated 104 officers who would have been "turned down" for bad landings if they had not been sent to him for treatment. Of these cases it was possible to trace 73 officially; 55 subsequently proved successful in flying, often on active service; 4 proved failures, primarily on account of their continued inability to land a machine even after treatment; 6 were found unsuitable for flying, but no details were obtainable as to their landings; while 8 were found unfit by medical boards for various reasons, such as neurasthenia or heart trouble, apart from or in addition to their eye trouble.

If the 6 found unsuitable for flying be added to the 4 definite failures, the figures give 86·3 per cent. successes after appropriate treatment.

It is to be noted that the opinion expressed as to the improvement or otherwise in the ability of these pilots to land is of particular value since, almost without exception, the pupils returned to the aerodrome from which they came for treatment, and in many cases to the same instructor. After returning from treatment many pilots were eventually posted overseas, some becoming engaged in the difficult work of deck flying.

Following the success of the above treatment at Lincoln, a school for cases of heterophoria was established under Wing-Commander Clements, on his transfer to the Royal Air Force Medical Service, at the Royal Naval College, Greenwich. It was subsequently transferred to Croydon Aerodrome. In accordance with an Air Ministry Weekly Order, various pupils who had had defects in their landings were sent to the school for eye training. On the completion of this, they returned to the squadron from which they came and at intervals of two months a report was furnished on their progress by the officer commanding and the instructor. Such reports showed approximately 90 per cent. successes after treatment.

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* Stereoscopic Charts compiled by Dr. David W. Wells, Boston, Mass., published by E. B. Meyrowitz, New York. (London branch, 1a, Old Bond Street, W.)

Tests for Vestibular Stability.

In certain allied countries, particularly in the United States of America, great importance was at first attached to the supposed " motion-sensing functions " of the vestibular apparatus. On them the success or failure of candidates for flying was believed largely to depend. The sensibility of the vestibular apparatus was tested by means of Barany's rotation tests, namely (1) the duration and extent of nystagmus after rotation to right and left, (2) the amount of " past pointing " and (3) the severity of the " falling error " after similar rotation. In Great Britain the importance assigned to these tests was not so great, and more reliance was placed upon the results of the tests for neuro-muscular co-ordination given below. When " rotation tests " were employed it was considered that more reliable information was obtained by the ability of a candidate to perform a definite action immediately after rotation, while the subject was still suffering from the vertigo consequent thereon. Generally speaking, therefore, " rotation tests " were only employed when a candidate had had previous symptoms, such as swing or train sickness, suggestive of hyper-excitability of the labyrinthine apparatus.

Major B. O'Reilly, Senior Medical Officer, Royal Air Force, Canada, and Captain W. G. MacKechnie came to an almost similar conclusion, as the result of nearly 8,000 examinations by the " chair " tests, emphasizing the importance of the degree of vertigo induced, particularly if associated with nausea or vomiting. "A final summing up of the relationship between vertigo, nausea, and vomiting in the air and disturbances in the chair seems to indicate that while there is no constant relationship between them, yet . . . . it would seem inadvisable to allow any pilot to fly who exhibited nausea or vomiting to any extent in the chair." Otherwise they could obtain no definite standards for flying efficiency by the rotation tests.

As the results of the examination by " rotation tests " in France of first grade pilots flying at the front, Major Sydney Scott reported that " the reactions to rotation may be excessive in some individuals and suppressed in others, but in neither case do the reactions of the semicircular canals seem to indicate an airman's probable flying ability."

On the other hand, Major Scott's observations showed conclusively the importance of efficient Eustachian tubes whereby an airman should be able correctly to regulate and equalize the continuous changes of atmospheric pressure experienced during flights from low to high and from high to low altitudes. In addition to deafness and distress, the unequal pressure in the ears resulting from unilateral obstruction may sometimes induce vertigo, vomiting, and forced movements which interfere with the proper control of the aeroplane.

At the admission of candidates, therefore, much importance is attached to the free ventilation and drainage of both Eustachian tubes.

Squadron Leader D. Ranken investigated the value of the "rotation tests" by the examination of civilian pilots. He found that experienced pilots have a tendency towards reactions below what are considered normal. Disturbance, present or past, of some other system of the body, as for example by influenza and malaria, may affect the labyrinthine reactions. He concluded that "where deafness is present no examination of a candidate or pilot is complete without a careful investigation of the functions and reactions of the semicircular canals of both sides. In the absence of a discovery of present or past signs and symptoms pointing to an aural affection, routine examination by means of Barany tests is superfluous, provided that the standard of the present examination schedule is maintained."

While acting as neurologist to the Central R.A.F. Hospital during the war, Dr. Henry Head made investigations using the rotation chair, not as a method of measuring the response of the semicircular canals, but as a means of inducing an abnormal reaction. He was anxious to determine, not the afferent results of such stimuli, but the way in which the patient could adapt himself to somewhat violent sensory impressions. The object was to examine his control in face of disturbances of equilibrium.

A healthy man responds in a certain way to rotation, although the degree of giddiness varies greatly. He found that in certain persons, who suffer from morbid phenomena in the air, the reaction is abnormal and excessive. It was frequently possible, by rotation, to induce physiological states and sensations analogous to those experienced in the air, though to a lesser degree. This was true, not only in cases of "giddiness," but also in those where the pilot has "fainted" in the air.

Dr. Head pointed out that complete adaptation to disturbances of equilibrium in the air is associated with automatic control of the afferent and efferent activities of lower levels of the central nervous system. A perfect pilot desires that his machine shall behave in a certain manner, and the evolution occurs.

This acquired faculty can be disturbed by any condition which leads to diminished control. The aviator may lose his capacity to fly in consequence of conditions that vary so widely as a gastro-intestinal attack or domestic anxiety. Exhaustion, insomnia, the strain of war flying, anxiety or fear, can all lead to defective afferent and efferent control. Efficient automatic response is no longer possible, and the pilot begins to fly badly and to make bad landings. This loss of control over the activity of lower levels may be manifested not only in bad management of the machine, but in some dangerous reaction such as " giddiness " or " fainting " in the air. When this abnormal reaction assumed the form of giddiness and nausea, it was found in most of the ten cases examined that the patient had suffered from some discomfort when he first went into the air. Enquiry usually revealed that he was unable to swing with pleasure as a child, and that he tended to be sick when travelling by train. On the other hand, all the five pilots who came under Dr. Head's care for " fainting " enjoyed their first flight and could swing with pleasure.

In the first group rotatory impulses, when released from control, manifested their influence in giddiness, usually accompanied by nausea. Amongst those who " fainted " in the air the resistance to vertiginous impressions was high and no excessive giddiness resulted ; but they induced the effects of shock with undue facility.

Tests for Neuro-muscular Co-ordination and Nervous Stability.

The following tests are applied to determine respectively the subject's condition in regard to equilibration, tremor and reflexes. The first two tests were originally introduced by Lieut.-Colonel Arthur Cheatle during his routine ear, nose and throat examination at the aviation candidates' medical board. The following instructions are given for carrying out these tests :

(i) *Test for Self-balancing.*—This is tested by requiring the candidate to stand successively on each foot, toes pointing forward, the other knee bent, legs not touching, eyes closed, and hands to sides. The minimum time for balancing is fifteen seconds in a good subject, and three attempts to carry out this test are allowed if necessary. Record, for example, as R. 15/1, L. 15/2, or in case of failure as O. The manner in which this test is carried out is important, as the individual may succeed in standing on one leg for fifteen seconds but be under erratic muscular control ; an entry should therefore be made whether steady (St.), fairly steady (F.St.) or unsteady (Ust.).

(ii) *Test of Balancing Rod.*—The balancing rod (Fig. 1) is placed upright on the board provided for the purpose about 1½ in. from the far end ; the candidate is required to take hold of the board between the fingers and thumb, and to raise it at arm's length from the table to the level of the shoulder and replace it, without upsetting the rod. This test should be performed with the right and left hand successively, and with the eyes open and shut. With the eyes open the test should be performed equally well with either hand ; with the eyes closed the left hand is usually less steady than the right. It should always be possible for a right-handed candidate to pass this test with the right hand, eyes closed, at least once in six attempts.

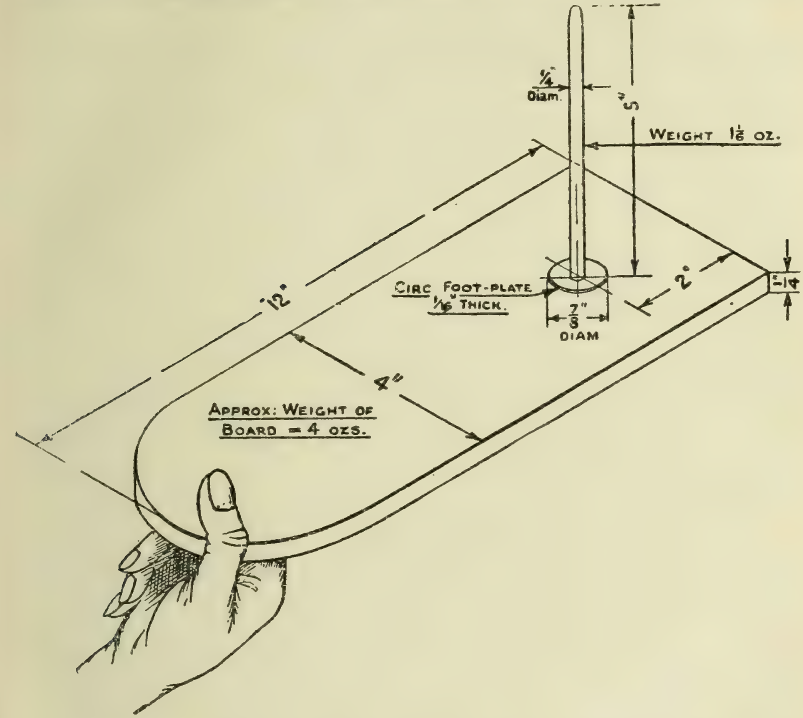
¼" Diam.
5"
WEIGHT 1⅙ OZ.
CIRC FOOT-PLATE 1/16" THICK.
7/8" DIAM
2"
¼"
12"
4"
APPROX: WEIGHT OF BOARD = 4 OZS.

Fig. 1.—Diagram of balancing rod

(iii) *Test for Tremor.*—This should be carried out by getting the candidate to stand with eyes shut, tongue out, arms extended in front and fingers spread out and slightly dropped. Care must be taken that the arm muscles are not rigidly contracted. The degree of tremor (if any) of eyelids, tongue, and fingers is noted. It is recorded as coarse or fine, slight, or marked.

(iv) *Knee-jerk.*—Responses to be graded as sluggish (–), normal (N.), brisk (+), and exaggerated (++).

Lieut.-Colonel Bowdler analysed the records of a series of candidates especially from the point of view of the association of signs of neuro-muscular incoordination and nervous instability with failure to train as pilot.

With the exception of the records of Group II, which represents pilots and pupils examined at aerodromes by Lieut.-Colonels Flack and Bowdler, the observations were obtained either from the original medical examination sheet or from medical reports made subsequently at the invaliding board. A pupil was considered successful if he had completed his training and obtained his wings ; an unsuccessful pilot was one who had been declared by the invaliding board permanently unfit for air work, or who had crashed fatally.

The cases whose records have been investigated and compared are included in four groups :—

Group I.—1,000 accepted candidates who ultimately became successful pilots. Records taken from original medical examination form, on admission.

Group II.—93 successful pilots and pupils. Of these 76 had qualified and had considerable flying experience, and 17 were successful pupils about to obtain their wings. Records taken on aerodromes.

Group III.—200 accepted candidates who eventually failed to qualify or crashed during training with fatal results. Records taken on admission.

Group IV.—40 pupils under instruction who failed in their training, and were declared permanently unfit by the invaliding board. Crashes are not included in this group. Records taken by the invaliding board.

The results of this analysis are shown in Table II :—

TABLE II.

	Group I.	Group II.	Group III.	Group IV.
	1,000 Successes. Records on Admission.	93 Successes. Records after Training.	200 Failures. Records on Admission.	40 Failures. Records by Invaliding Board.
	Per cent.	Per cent.	Per cent.	Per cent.
Poor equilibration alone	1·6	5·3	8·0	5·0
Marked tremor alone	2·0	6·4	5·0	20·0
Exaggerated reflexes alone	3·9	2·1	2·4	2·5
Combination of two of the signs above mentioned . .	·5	0·0	3·0	40·0
Combination of three of the signs above mentioned . .	·1	0·0	1·0	17·5
Total percentage presenting signs . .	8·1	13·8	19·4	85·0

It is shown by this table :—

(1) That the percentage of cases which gave a bad reaction to the tests is very much greater among the failures—prospective or actual—than among the successes.

(2) That these signs of instability are more obvious in men who have actually flown, whether they have graduated successfully or have failed, and that therefore they may be regarded as signs of the result of " stress." The results in Groups II are worse than in Group I, and similarly those in Group IV are much worse than those in Group III.

(3) That from comparison of the percentages presenting the various signs or combinations of signs in Groups I and III, the presence of poor equilibration or marked tremor seriously diminishes a candidate's chances of gaining his wings. Indeed, it is probable that " fair " equilibration and a moderate degree of tremor are indicative of likely failure to qualify as pilot. Exaggerated reflexes alone, on the other hand, appear to be unassociated with any abnormal tendency to failure. Combinations of pronounced signs are so rarely observed among candidates who were accepted that the number of cases presenting them in the first three groups is extremely small. Such figures as are available, however, show the inadvisability of accepting candidates exhibiting these signs in combination. This view receives additional support from a consideration of the figures in Group IV, which show the condition, as regards these points, of forty unsuccessful pupils on their appearance before the invaliding board after failure had occurred.

It is interesting to note that exaggerated reflexes and pronounced tremor in combination occurred in 22·5 per cent. of these cases, exaggerated reflexes and poor equilibration in 2·5 per cent., pronounced tremor and poor equilibration in 15 per cent., and all three signs in 17·5 per cent.

As regards the neuro-muscular system, therefore, these conclusions may be drawn. First, that exaggerated reflexes alone appear to have no prognostic value, and their presence may be disregarded.

Second, that marked tremor and poor equilibration may be taken as signs of poor neuro-muscular stability. The case of a candidate who shows one of these signs only should receive very careful consideration. It is justifiable to assume that his chances of making a successful pilot are much less than normal.

Third, that a candidate who shows both marked tremor and poor equilibration is probably unfitted for air work and should be rejected forthwith, unless his condition can be ascribed to some temporary indisposition. The chances are not in favour of his being able to train successfully and, even if this were accomplished, his career as a useful pilot would probably be very short. In such circumstances the expense to the country, the danger to life involved, and the waste of time to instructors are considerations that render the acceptance of such a candidate unjustifiable.

Dr. Henry Head investigated the value of some of the above tests upon his patients at the Central R.A.F. Hospital. The material at his disposal consisted of 30 cadets, in 22 of whom he was able to obtain the after-history; of 20 pupils who were rejected for some inability to fly of a non-medical nature; and of 30 cases where a pilot or observer came to him on account of some disability such as vomiting, or fainting in the air. In addition he obtained useful experience from other patients under his care.

He came to the conclusion that with such material as is met with in the R.A.F., consisting of young men in whom gross organic disease is almost absent, these tests revealed the condition of physiological or psychical control. Such control might be defective from innumerable causes, some of the most potent being fatigue, physical or mental stress, anxiety and fear.

In regard to tremor, he found that in every case of a pupil, pilot or observer that came under his notice, this sign was associated with some obvious cause. In a certain number it was due to alcoholic excess, and it was particularly evident in those pilots who took alcohol in order to be able to carry on their work. But apart from alcohol, it was one of the commonest signs of stress of war service and was particularly frequent in those candidates who had already served in the infantry at the front. It was almost universally present in those officers who were admitted to hospital for some functional psychoneurosis or shell shock.

Tremor of the hands was a not infrequent sequel to malarial infection; it was more evident in delicate and precise movements, such as shaving, and the handwriting might be affected. Such unsteadiness came out particularly well also when attempting to balance the rod on a flat board. Excessive smoking, especially the perpetual use of cigarettes, was responsible for much tremor of the hands in members of the R.A.F. "Thus, tremor is evidence of some disordered functional state, and should be looked for definitely in the course of the routine medical examination of candidates or pilots."

In respect of the knee-jerk, Dr. Head pointed out that a condition not infrequently called " exaggerated knee-jerks " was, however, really an indication of loss of general control and had nothing to do with tendon reflexes.

" This ' exaggerated knee-jerk ' is an uncontrolled reaction to a gentle blow and the same person will be found to start at a sudden noise. This ' general response ' to tapping the knee is a valuable sign of control, but is no indication of the condition of the deep reflexes. It is usually associated with a state of anxiety and is more likely to be found in unfit pilots than in candidates for the R.A.F."

Dr. Head pointed out that the tests of standing on one foot with the eyes closed and of balancing a rod on a flat board, are not tests for " muscle sense " or " vestibular stability," in the class of young men from whom the pilots and candidates of the R.A.F. are drawn. Failure to pass these tests, however, indicates some want of afferent or efferent central control.

As regards the " standing on one foot test," he found among 42 healthy individuals 10 cases where this test could not be carried out perfectly. On the other hand, of 24 pilots and pupils who ceased to fly because of some morbid condition in the air, 15 showed considerable difficulty in balancing themselves on one foot.

In the " balancing the rod test " there was nothing to show that there was any material difference in behaviour between those who could and those who could not fly, provided they were physically healthy. Out of 28 pilots who had suffered from pathological states in the air, 14 were tremulous and all but one showed difficulty in balancing the rod on the board. In the same way, out of 50 cadets and rejected pupils, 11 showed some tremor of the hands, and all of these failed to balance the rod satisfactorily.

Dr. Head pointed out that it must not be supposed that this test is only another means of discovering tremor. Amongst 28 pathological cases there were 7 persons who were not tremulous but could not balance the rod with normal certainty. In the same way, amongst 30 cadets and 20 rejected pupils, 9 could not carry out this test satisfactorily, though free from tremor. In almost every instance of this class a special note was made that the failure was due to erratic conduct, carelessness, want of resolution, or defective comprehension of the task and the best method of carrying it out. In other cases the movements were " clumsy " and stiff," or the subject seemed " utterly worn out " and " tired."

"Thus we may conclude that, provided the subject of examination is in perfect physical health, this test has no direct bearing on his capacity to fly a machine heavier than air. But, on the other hand, it is a useful method of detecting states of exhaustion, flying-stress, insomnia, and other neuropathic and psychopathic conditions, in an early stage of development. There is no difference in principle between the test carried out with the eyes open or shut. The latter is a more difficult task, and therefore tends in most cases to show defects sooner than when the balance is guided by sight."

Tests for Circulatory Efficiency.

The chief tests applied for this purpose were (1) the comparison of the pulse rate sitting at rest, standing, and after graduated exercise, and (2) the measurement of the systolic and diastolic pressures.

The following directions were given to medical officers for testing the response of the pulse to exercise :—

Response of Pulse to Exercise.—The pulse rate is taken first sitting and then standing. If the rate is unsteady it should be counted in periods of five seconds until a steady rate is obtained.

The candidate is then put through a regulated exercise, which should be carried out as follows. Standing before a chair he places one foot upon the seat of the chair, and steadily raises and lowers his body to and from the height of the seat five times in fifteen seconds, one foot being retained on the chair throughout. The examiner should regulate the speed in the following way. Standing beside the candidate, holding the wrist with his fingers on the pulse, the examiner in each period of three seconds swings the arm forward and backward to indicate the time of raising and lowering the body.

The subject still standing, the examiner then counts the pulse in five-second periods, notes the acceleration and the time taken to return to the previous standing rate.

Lieut.-Colonels Bowdler and Flack tested the value of the above tests upon a number of successful flying officers engaged

TABLE III.

	Pulse rate Standing.	Pulse rate after Exercise.	Increase.	Time taken to return to Standing Rate.
				(Seconds)
Flying school instructors (29)*	87	114	27	20
Test pilots (17)	84	109	25	25
Home Defence (30)—				
Low	101	126	25	16
High	85	110	25	18
Successful Pupils (17) ..	85	109	24	21
Unsuccessful Pupils (8) ..	85	121	36	23

* The figures in brackets represent the number of officers examined.

upon different forms of aerial work at various flying stations. In addition a number of successful and unsuccessful pupils were also examined. The results are given in the Tables III and IV.

Blood pressure.—The average systolic and diastolic pressures in the series are given below. These were taken with the arm at heart level and also with the arm raised through an angle of 120°. Both the systolic and diastolic pressures were taken by the auscultatory method, the systolic pressure being read preferably at the point of reappearance of the pulse, on coming down after previous obliteration by the armlet pressure.

TABLE IV.

	Arm at Heart Level.		
	Systolic Pressure.	Diastolic Pressure.	Pulse Pressure.
Flying school instructors..	120·6	89·3	31·3
Test pilots	121·4	82·8	38·6
Home Defence—			
Low	119·1	77·7	41·4
High	122·5	74·9	47·6
Successful pupils	115·7	74·1	41·6
Unsuccessful pupils	122·1	68·4	53·7

From a consideration of these observations it was possible to draw the following conclusions :—

(*a*) That the observation of increase in pulse rate after exercise, and the time it takes to return to the rest rate, is a useful method of testing the functional efficiency of the cardio-vascular system. With the method of exercise adopted an increased rate of over 25 and a return period of over 30 seconds are points calling for careful consideration of the candidate's cardio-vascular system. It is to be observed that a rest rate above normal, especially if influenced by respiration, is not regarded as necessarily throwing doubt upon the functional efficiency of the cardio-vascular system. A pulse of 60 to 72 little raised by exercise (10 beats per minute), and returning to normal in ten seconds, appears to be a good sign, generally associated with excellent physique and good stability of the nervous system.

(*b*) That a diastolic pressure below 70 mm. Hg, combined with a pulse pressure greater than 50 mm. Hg, is strong evidence that a cardio-vascular system is unsuited for air work. From a consideration of blood pressure records the conclusion was, formed that stress of service or high flying eventually produces in an individual previously fit a low diastolic pressure and a big pulse pressure, due probably to lessening of vaso-constrictor tone of the arterioles.

Application of the above standards among the various groups examined worked out as follows :—

TABLE V.

	Number Examined.	Number of P.P. over 50.	Per cent. P.P. over 50.	Number of D.P. below 70.	Per cent. D.P. below 70.	Number of men with P.P. 50 + and D.P. 70 –	Per cent. with P.P. 50 + and D.P. 70 –
Flying school instructors	29	0	0	0	0	0	0
Test pilots	17	4	23·5	3	17·6	2	11·7
Home defence—							
Low	15	3	20·0	1	6·6	1	6·6
Scout	15	6	40·0	3	20·0	3	20·0
Pupils under instruction—							
Successful	17	4	23·5	5	29·4	0	0
Failures	8	5	62·5	4	50·0	4	50·0

It should be borne in mind that, in the case of pilots, recent nerve strain was common, and in the Home Defence squadrons the pilots were being subjected to fairly constant stress, and there is every reason to believe that with a period of rest these would conform to the requisite standard. The instructors at flying schools and the successful pupils satisfied this test without exception, while four of the eight unsuccessful pupils would have been rejected on the score of cardio-vascular deficiency. The other unsuccessful pupils, it should be observed, were of the nature of the " temperamentally unfit." The test should not be applied rigidly without consideration of other points in the candidate's condition.

Indeed, in all subjects failing in the tests, particularly border-line cases, other points such as soft abdominal wall, splashing stomach, engorged jugular veins, reflexes brisk or exaggerated, tremors, poor balance and local signs, were considered. In this series it was found that failure to pass this test of blood pressure was almost invariably associated with two or more of these abnormal physical signs.

It may be considered, therefore, that the ideal pulse for a flying officer has a small range between systolic and diastolic pressures (20–30), with a rest rate increased at most 20–25 by exercise and returning to the rest rate in 10 to 15 seconds.

Making allowance for active service conditions, this view is confirmed by Lieut.-Colonel J. L. Birley, who examined a number of pilots in the field. He found that " whereas the normal stable individual, when due for a rest after 150 to 500 hours' war flying, preserves a comparatively slow pulse and a resting blood pressure within normal limits; the unstable individual, on the other hand, with little war flying to his credit, who has failed to rise to the occasion or has succumbed to some minor accident, has a definitely faster pulse and a blood pressure which is frequently abnormally high (such as 170–180 mm. Hg).

This increased blood pressure was in no case associated with arterial or renal changes and was looked upon as an indication of the strain of active service. It is probable that before such strain was encountered these individuals had a high pulse pressure associated with a relatively low diastolic pressure.

Tests for Respiratory Efficiency and Endurance.

The following were the tests employed by the Royal Air Force. Although designed primarily as tests for respiratory efficiency, they also yielded valuable information in regard to the circulatory and nervous systems, as well as being of considerable service in forming an opinion of the temperament of the subject.

Test No. 1 *: Breath-holding Test.*—The candidate is asked to expire as deeply as possible, preferably audibly, and then to fill the lungs fully, but not to absolute distension, and to hold the breath with the nose clipped or held. The reason for the audible expiration is that it has been observed that some subjects suffering from stress have lost the power of expiring fully, and a marked shortening of time taken to expire as fully as possible may afford an indication of such loss of power. The time for which the breath is held is noted, and the candidate is then asked the reason for giving up. These should be recorded. The candidate must not be told the significance of the test, nor the time he is expected to hold his breath. On no account may he time himself.

Normally, an answer such as " I had to give up," " I felt I should burst," " I wanted to breathe," is given. Subjects suffering from marked disability at altitudes almost invariably return an abnormal answer, *e.g.*, " I became giddy or dizzy," " Things went blurred," " The blood rushed to my temples," " I began to feel squeamish." Where the answer is deemed not to be normal the candidate's own words should be given.

This test is believed to afford indication of :—

(*a*) the stability of the respiratory centre, and indirectly of the nervous system generally;

(*b*) the likelihood, when the time is short and an abnormal answer is given, of the subject suffering from oxygen want at altitudes;

(*c*) the candidate's resolution to " carry on " under conditions of stress.

Test No. 2 *: Expiratory Force.*—The candidate is asked to hold his cheeks with the thumb and forefinger of the left hand and steadily to blow the mercury column of the standard U-tube up as high as possible with the scale turned away. Several mouth-pieces must be kept in disinfectant and the mouth-piece changed for each candidate. On no account must the candidate be allowed to swing the mercury up violently, and in all cases the height of any initial swing is to be disregarded. The reason for holding the cheeks is that it has been found that in some cases the mercury may be forced up to abnormal heights by the action of the cheek muscles. The number of mm. Hg blown is recorded. The candidate is then asked to repeat the performance while looking at the column. The resolute candidate may, under these conditions, considerably pass the effort which he did not see, in this way affording some indication of his mental make-up. On the other hand, a subject who is not trying may give very discrepant readings. With the manometer again turned away, he may, by encouragement, be made to surpass his previous efforts, although this would be impossible if he had done his best whilst looking at the manometer scale.

Test No. 3 : *Vital Capacity.*—Several mouth-pieces must be kept in disinfectant and the mouth-piece changed for each candidate. Preferably, five observations should be taken and recorded in litres and fractions of a litre.

The candidate sits opposite the spirometer, the dial being so placed that he cannot see the readings. Neck, chest, and abdomen must move freely. He is directed to fill his lungs to their maximum capacity, and then, while holding his nose, to expire as completely as possible at a fair rate through the meter.

The adequacy or otherwise of the vital capacity for the weight, stem length, and chest circumference of the candidate, can be found by reference to tables calculated for these from the formulæ suggested by Dreyer.

Test No. 4 : *Endurance Test* (*Mercury U-tube Test*).—This test is performed as follows :—The candidate is asked to empty the lungs, fill up, blow the mercury to the height of 40 mm. and hold it there without breathing for as long as possible, the nose being clipped. The average time in the large number of cases tested is fifty seconds. A time less than forty seconds is unsatisfactory. An essential adjunct to this test is the behaviour of the pulse, which is counted for every five seconds during the time that the mercury is sustained. In fit subjects there is generally either no appreciable change of rate of the pulse or a steady slow rise in rate, which is sustained most of the time. For example, the pulse-rate may rise gradually from 72 to 96 or 108, according to the time the breath is held. In some subjects the pulse may rise almost at once from 72 to 84 or 96, and be sustained there. A large rise in rate, *e.g.*, from 72 to 132 or 144, is unsatisfactory. In pilots suffering from " flying strain," a characteristic response is for the pulse to jump up to a very quick rate during the fifth to the tenth or fifteenth second, and then to fall away in rate to normal or even below normal.

In such cases the pulse, with a normal rate of 84 at start, rises between the fifth and tenth seconds to 144, or sometimes is almost impalpable, falling away after twenty to twenty-five seconds to 72, or even 60. Such cardio-motor instability is an adverse factor in aerial work, and is an indication for rejection. Other points in the examination should, however, be taken into consideration. The test is to be recorded by first noting the number of seconds during which the mercury column is sustained and then writing down the pulse-rate at five-second intervals, *e.g.*, 50—P.6677789888, the time taken to blow the mercury to 40 mm. being ignored.

This test affords information as to the stability of the medullary centres and of the power of resistance to fatigue.

Various considerations led to the conclusion that the first breakdown in the bodily symptoms is probably associated with the respiratory mechanism, which, becoming defective in working, reacts through inefficient respiratory ventilation upon the cardio-vascular and nervous systems, thereby bringing out secondary signs of cardio-vascular and nervous debility. In support of this view, it was early observed that pilots, stated to be suffering from stress, suffered from breathlessness and manifested inability to blow hard or expire deeply. Investigations were therefore made into the condition of the respiratory mechanism of successful and unsuccessful pilots. The first test devised was that of holding the breath. Preliminary figures obtained from successful pilots showed that on an average these officers could hold their breath under the conditions of the test for sixty-nine seconds, whereas many officers who were attending medical boards owing to their inability to fly high, could hold the breath, generally speaking, only for twenty to forty seconds, the performance being attended usually with a considerable degree of discomfort. This is shown in the following table of results obtained quite early in the investigation :—

TABLE VI.

Cases.	Vital Capacity in c.c.	Time Breath held in seconds.	Remarks after holding Breath.	No. of Hours Flying.	Max. Height in feet.	Remarks.
Case 1 ..	2,100 (max. 2,400)	25	"Made him fuzzy."	10½ (dual)	6,000	Giddiness and blurring of vision when flying at 6,000 ft. Bag method broke down at 6,000 ft.
Case 2 ..	4,100	42 (max.)	"All out, dashed uncomfortable."	33	9,500	Nausea above 7,000 ft. (only three times ever above this : very bad at 9,500). Bag experiment 9,000 ft.
Case 3 ..	4,200	31	—	4 (as observer)	6,000	Great difficulty in breathing, and dizziness at 5,000 ft. after four hours' flying.
Case 4 ..	3,800	19	"Head inclined to swim."	6 (dual)	6,000 (once)	Has fainted three times below 5,000 ft. With bag method nearly fainted at 3,000 ft.
Case 5 ..	3,750	34	"Headache and throb."	16 (solo)	5,000 (as observer ; 3,000 as pilot).	Headaches worse after one hour ; has had concussion. By bag method "oxygen-want" at 4,000 ft.
Case 6 ..	3,700	36	"Little dizzy."	—	—	Goes dizzy and sick in air with bag method. Broke down at 4,000 ft.
Case 7 ..	3,500	21	"Sort of funny."	2 (solo).	—	Dizzy every time he went up.
Case 8 ..	3,700	40	"Head bursting, especially at temples."	Pilot under instruction	—	Bad pressure in head, and discomfort, especially about 2,000 ft.
Case 9 ..	2,800	30	"Felt little giddy."	Just got wings.	5,000	Feels giddy and faint above 5,000 ft. By bag method broke down at 4,500 ft.
Case 10 ..	3,300	21	"Little giddy."	8	2,000	Giddy above 1,000 ft.
Case 11 ..	3,200	26	"Uneasy."	25	12,000 (once as observer).	Solo. Feels faint over 2,000 ft., "oxygen-want" and "nerves." By bag method, broke down at 8,500 ft.
Case 12 ..	3,100	45	"Head seems to swell."	60	10,000 (once as observer).	At 6,000 ft. gets less alert, then not all there. With bag method went very dazed and reached 12,000 ft.
Case 13 ..	2,700	15	"Blood rushing to temples visible."	Pilot under instruction	2,000	Gets headache and blood rushing to temples at 2,000 ft. Was stood off flying, now permanently unfit as pilot.

It will be seen that the officers included in the above table had but a relatively short flying experience. With the introduction of the breath-holding test, during the past years, it has become rarer for officers admitted to flying to complain of untoward symptoms during their first few hours in the air. The breath-holding test was primarily devised as a test for oxygen-want, since during the holding of the breath the subject is gradually submitting himself to a rarefying atmosphere, as the oxygen in his lungs becomes used up. Since, however, the conditions arising during the holding of the breath are not strictly comparable to those of an ascent, this test was, during the period of investigation, correlated with other experiments in which such complications as the accumulation of carbon dioxide and the embarrassment of the respiratory circulation were eliminated. The results showed that these complications do not vitiate the results of the breath-holding test, and for practical purposes may be ignored. That the test is in part one for oxygen-want is shown by the fact that, if the breath be held with the lungs full of oxygen instead of with the lungs full of air, the time during which the breath is held is increased from two to two and a half times.

Lieut.-Colonel A. P. Bowdler gives the following figures which serve to demonstrate the value of the breath-holding test in the selection of aviation candidates.

TABLE VII.

Table showing percentage of pilots of various breath-holding capacities breaking down within one year of acceptance by the Aviation Candidates' Medical Board. No results of crashes are included in these figures.

Breath-holding time in Seconds.	No. of Pilots.	Permanently or temporarily unfit for long periods during first year.	
		No.	Per cent.
40—50	131	17	13·0
51—60	273	28	10·2
61—70	208	16	7·7
Over 70	263	18	6·8

Concomitantly with the breath-holding test, the vital capacity of a number of subjects was measured by means of a modified gas-meter, through which the subject, after full inspiration, expired to the fullest extent. As shown in

Table VI, it was found that a small breath-holding capacity was frequently associated with a small vital capacity. It was noticed also that with the onset of flying stress the breath-holding power and the vital capacity gradually diminished. Owing to an observed diminution of expiratory force, the test of blowing up a column of mercury in the U-tube manometer was devised. The test of supporting 40 mm. of mercury with the breath held was introduced as an "endurance test"; the subject originally being required to blow up the mercury at stated intervals, the supplemental air was frequently measured by getting the subject to expire to the utmost after quiet expiration.

A research was carried out with these tests upon a number of successful officers. In addition, a number of officers returning for a rest, as well as officers who had broken down owing to stress, were examined. A number of candidates, both British and American, were also examined, as well as pilots under instruction. The following table shows the first results obtained.

TABLE VIII.

Subjects.	No. examined.	Breath held in seconds.	Vital Capacity in c.c.	Supplemental Air in c.c.	Expiratory Force in mm. Hg.	Sustaining 40 mm. Hg, in seconds.
Fit instructors	22	67	4,062	1,620	112	52
Do. do. (minimum result)		46	3,300	1,000	80	43
Home defence pilots	24	72	3,940	1,496	119	50
British candidates	23	69	3,823	1,590	106	52
U.S. candidates	7	66	3,814	1,386	116·4	53·5
Delivery and test pilots	10	57	3,620	1,050	108	40
Pilots returned for rest	17	57	3,897	1,423	95	40
Pilots training for scouts ..	15	62	3,820	1,433	96	49
Pilots taken off flying through strain	27	49	3,480	1,134	74	25
Hospital cases	55	54	3,560	—	87	35·5

From the above figures it is seen that for the expiratory force test 80 mm. Hg should be taken as a minimum. For the test of sustaining 40 mm. Hg with the breath held, forty seconds should be regarded as the minimum time. If below this it would be advisable to limit flying both as to hours and height, and, if much below this figure, to take the subject off flying for a time altogether.

These tests in combination were of use in indicating the powers of endurance of the subject for high or prolonged flying, and also of value in assessing the degree of shock sustained by a pilot in so-called "minor" crashes. It is of interest that during the stage of investigation, while the value of this test was being investigated, a number of subjects found unfit at the aviation candidates' medical board were also found unfit on the test.

In Table IX are seen the results of the examination of thirteen candidates previously definitely rejected by the assessors and of five candidates about whom they were doubtful.

TABLE IX.

Cases.	Age.	Time breath held in secs.	Vital capacity in c.c.	Expiratory Force in mm. Hg.	Time in seconds of sustaining 40 mm. Hg by blowing.
Rejected—					
Case 1	$17\frac{11}{12}$	55	4,200	80	42
,, 2	$17\frac{11}{12}$	84	4,300	60	25
,, 3	18	53	3,700	55	32
,, 4	18	66	3,800	130	30
,, 5	$17\frac{11}{12}$	53	2,800	60	25
,, 6	18	48	3,600	70	27
,, 7	$17\frac{11}{12}$	44	3,400	120	35
,, 8	18	85	2,750	100	28
,, 9	$17\frac{11}{12}$	71	2,400	100	50
,, 10	19	50	3,100	60	20
,, 11	19	63	—	60	40
,, 12	19	42	3,800	40	33
,, 13	23	42	4,200	60	25
Doubtful—					
Case 1	$18\frac{1}{12}$	64	—	60	33
,, 2	22	61	4,100	100	30
,, 3	$20\frac{2}{12}$	63	4,300	60	35
,, 4	$21\frac{6}{12}$	55	4,100	80	37
,, 5	$18\frac{2}{12}$	48	3,800	100	35
Average	—	58	3,650	77	32

It will be seen that these cases are all found unfit in some respect or other by the tests employed. Further experience has fully confirmed the value of these tests in the selection of cadets. Experience has shown, however, that when the 40 mm. Hg test is used with candidates for admission, the average time of fifty-two seconds should be taken as the standard.

It was found that, generally speaking, all hospital cases except psychopaths failed to pass these tests when taken as a whole. It was noticed also that after dysentery or malaria, subjects frequently failed at these tests, thus confirming the opinion formed clinically as to the injurious effects of these diseases.

Subjects turned down from training were in many cases also found unfit by these tests. For example, in the first 22 of over 300 such cases examined, the expiratory force averaged 84·5 mm. Hg, while the sustaining 40 mm. Hg test worked out at 30·8 seconds.

In France, the tests with the U-tube manometer formed a basis for the assessment of the temperament and efficiency of the subject examined. The results obtained are tabulated below with the pulse rate sitting, standing and after exercise :—

TABLE X.

Subject.	No. of Cases examined.	Expiratory Force in mm. Hg.	Seconds of sustaining 40 mm. Hg.	Blood Pressure in mm. Hg	Sitting Pulse.	Standing Pulse.	Exercise Pulse.
I.							
All pilots and observers on transfer to Home Establishment for a rest	91	116·6	46·7	123–78	72	85	95
(*a*) Bristol fighter and D.H.	20	130·5	41·7	121–74	71	84	93
(*b*) Scouts	26	108·5	47·2	121–79	70	83	90
(*c*) Artillery	24	119·3	43·5	125–80	71	84	94
(*d*) Night	21	103·6	45·7	127–78	76	89	100
II.							
All concussion cases	24	104·0	38·1	127–81	77	88	99
(*a*) Granted sick leave or returned to duty ..	12	120·4	48·6	131–85	74	85	93
(*b*) Evacuated sick to England	12	87·6	27·6	123–76	79	91	103
III.							
Permanently unfit	29	76·0	28·0	130–82	87	100	110
IV.							
Temperamentally unfit ..							
(*a*) By executive officers ..	8	106·0	45·0	125–81	69	80	88
(*b*) By medical officers ..	28	87·0	28·8	130–83	80	89	98
(*c*) Psychopaths	9	112·0	48·2	121–79	75	87	94

From the above table it is seen that pilots and observers, whose condition, in the opinion of their commanding officers, warranted their transfer to England for what was somewhat euphemistically termed a rest, preserve a comparatively high degree of physical fitness as judged by the tests employed.

Night-fliers, although having less hours in the air to their credit, were on the whole less fit than day-fliers, a condition attributable to their abnormal mode of life and lack of exercise and sleep.

Other groups in which the manometer results attain a high level are individuals who have recently sustained concussion, which had affected them so little as to warrant their return to duty either in a few days or after three weeks' sick leave; psychopaths who did not wish to continue flying; and a few cases, reported on as temperamentally unfit by executive officers, in which medical confirmation was lacking. All these cases were about equally fit judged by the manometer and pulse rates.

The value of the manometer test was confirmed in the following groups of cases:—

(i) Concussion cases evacuated to England.
(ii) Permanently unfit for flying on medical grounds.
(iii) Temperamentally unfit (excluding psychopaths).
(iv) Pilots taken off flying through strain.

Judged by the manometer, these groups are about equally unfit, and had also pulse rates considerably above normal.

The results also showed that the "sustaining the mercury" test had a value altogether apart from flying in general and from high-flying in particular, and that this value consisted in the assistance which it affords in assessing both the degree of shock sustained by the nervous system and also the susceptibility to shock. Looked at in this way, it is a test not so much for fatigue as for susceptibility to fatigue.

In addition to the tests already mentioned, Captain H. C. Bazett showed that the determination of the tidal air, respiratory rate, and ventilation per minute are of particular value in assessing the power of the subject to withstand high altitude. His results were classified according to three groups—those with a history of being good at altitudes, those with a history of being bad, and those whose power of standing high altitudes has never been put to any severe test. The results are seen in the following table:—

TABLE XI.

	Average Hours flown.	Exp. Force in mm. Hg.	40 mm. Hg test in seconds.	Vital Capacity in c.c.	Ventilation per minute in c.c.	Resp. Rate per minute.	Tidal Air in c.c.
Good at altitudes (26)	240	96	57·3	4,260	6,970	14·1	523
Bad at altitudes (28)	131	81·8	38·7	3,770	8,500	20·1	452
"Altitude" capacity not tested by actual high flying(19)	175	100·8	47·4	3,850	8,500	15·4	588

It will be noticed that the third group figures are intermediate between those of the first and second in the duration of the

40 mm. test, in the respiratory rate and in the vital capacity, while the ventilation per minute is lower in the first group than in either of the other two. The expiratory force was higher in the third group than in the first, but this is probably to be accounted for by the smaller number of the hours flown by the last group, so that fatigue played a smaller part.

It appears, therefore, that, besides the information to be obtained from the U-tube tests, a large vital capacity, a low ventilation per minute, and slow respiratory rate are all of great assistance to the high-flying pilot. It appears, too, that the vital capacity should be considered in relation to the air consumption at rest, since the man with a high air consumption will necessarily require a larger chest in order to maintain the same reserve.

The ratio of ventilation per minute to vital capacity is 1·55 in the first class, 2·3 in the second, and 2·26 in the third. Since a slow respiratory rate seems also to be an advantage, an artificial factor was deduced expressed by the formula—

$$\frac{\text{Respiratory rate} \times \text{ventilation per minute}}{\text{Vital capacity}}$$

a figure of 30 being taken as a standard.

If the cases are examined to decide what percentage falls below certain standards, the following results are obtained :—

TABLE XII.

Test.	Percentage below Standard. Groups. I.	II.	III.
Expiratory force minimum standard (80 mm.)	34·6	55·5	36·8
Expiratory force average standard (105 mm.)	69·3	74·1	73·7
Duration at 40 mm. minimum standard (40 seconds)	15·4	48·2	31·6
Duration at 40 mm. average standard (52 seconds)	38·5	89·0	68·4
Respiratory rate (standard 16)	15·4	57·2	36·8
Ventilation to vital capacity ratio (standard 2·0)	20·0	64·3	47·3
Formula (standard 30)	24·0	71·5	47·3

The above results show that the tests introduced by Captain Bazett afford valuable evidence as to the subject's capacity for high-flying. His observations received confirmation from the work of Dr. Grace Briscoe who independently carried out somewhat similar experiments at the Central R.A.F. Laboratory, Hampstead.

Tests for " Oxygen Want."

Much information in regard to the ability to withstand " altitude " effects has been obtained by the employment of rarefaction chambers, and from the use of special apparatus, such as the Dreyer nitrogen-oxygen apparatus, or the rebreathing apparatus employed by the United States authorities.

A rarefaction chamber consists generally of a large cylindrical steel tank, in which reduction of pressure is brought about by means of a motor-driven vacuum pump. Probably the best yet devised is that used by the Americans. While much is to be said for the use of such chambers, experiments with them always take a considerable amount of time, and therefore more rapid methods are generally preferable. In addition, there is the fact that unless the ventilation of the chamber is perfect, the altitude recorded through diminution of pressure is not necessarily the correct altitude reached, since it is possible that the accumulation of any carbon dioxide vitiates the result, as does also the use of oxygen by the observer. If oxygen is not used by the observer, he is submitted to the effects of rarefaction in dulling mental perception and his observations are not always trustworthy.

For the study of the effects of " oxygen want " on flying men, whether for selection or for the purpose of testing staleness, flying fatigue or other symptoms that may develop as a result of continued flying, particularly at high altitudes, it is important to make use of a procedure that eliminates other complicating effects of a decreased atmospheric pressure on the organism.

The advantages of the Dreyer method described below are that :—

(1) The apparatus is readily put together, and can be used in any place, either indoors or in the open.

(2) It does away with all interfering influences of reduced pressure on the internal ear or other organs, and thus allows the pure study of the effects of decreased partial pressure of oxygen.

(3) It is possible to investigate not only the changes in reaction time by means of specially adapted instruments, but also to conduct practical experiments, as, for instance, to determine the readiness with which a pilot or observer can orientate himself, aim, fire a gun, and so on.

(4) The person conducting the experiment is not himself incapacitated by the effects of "oxygen want," nor does he have to breathe oxygen to obviate these effects, as would be the case if a rarefaction chamber were used.

The Dreyer Method.—The arrangement of the apparatus is seen from the diagram (Fig. 2).

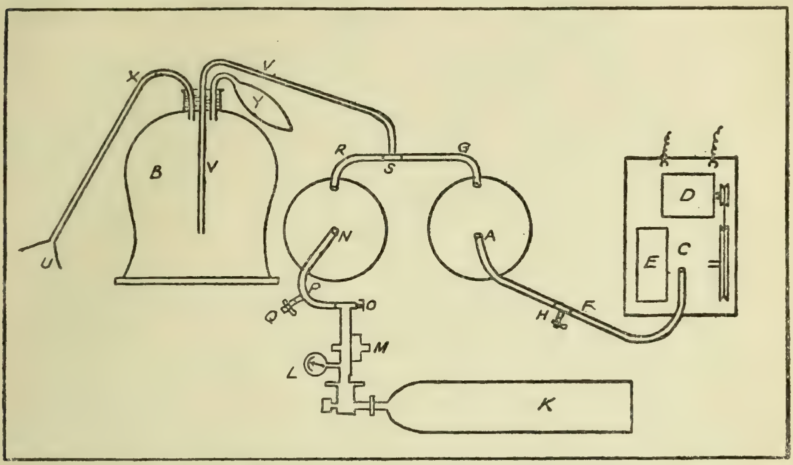

Fig. 2.—Dreyer method of testing oxygen want.

A blower (C) worked by a small electric motor (D), governed by a resistance (E), allows different quantities of atmospheric air to be passed through an accurate gas-meter (A) by means of a tube (F) of wide bore. From the gas-meter (A) ("air-meter") an exit tube (G) of similar bore is connected with a large container (B) ("breathing chamber") of a capacity of about 30 to 40 litres, preferably about 35 litres.

A T-piece (H) is inserted into the tube (F) connecting the blower with the air-meter. To the free end of the T-piece is fixed a short length of thick-walled india-rubber tubing of a small lumen, to which a screw-clip is attached. By this means a very fine regulation of the quantity of gas passing through the air-meter can be obtained, if a more delicate regulation than can be secured by the electrical resistance is required. A nitrogen cylinder (K) of a capacity of about 1,000 to 1,500 litres (at 150 atmospheres pressure), and provided with a manometer (L), a reduction valve (M), and, peripheral to the reduction valve, a stopcock (O) allowing one to regulate the nitrogen delivery, is connected up by means of wide tubing (P) to a gas-meter (N) ("nitrogen-meter") exactly similar to the air-meter. A T-piece (Q), fitted with thick-walled india-rubber tubing of a small lumen, and provided with a screw-clip for fine adjustment of the quantities of nitrogen passing through the nitrogen-meter, is inserted into the tubing (P) leading from the nitrogen cylinder to the meter. The exit tube (R) from the nitrogen-meter (N) is connected by means of a T-piece (S) to the exit tube (G) leading from the air-meter (A). The inlet tube (V), *i.e.*, the joint exit tube from the two meters, should be passed near to the bottom of the breathing chamber.

The reduction valve made use of should allow quantities of nitrogen of not less than 16 litres per minute to pass through the meter, and the stopcock should allow the regulation of quantities from a trace of gas up to a delivery of 16 litres per minute.

Into the breathing chamber is further fixed a wide-bore exit tube (X) connected up with a face mask (U).

The mask found preferable for use is the French " Tizot " mask. It is a tight-fitting mask made of pure india-rubber, fitted with a very light " knife " valve, arranged in such a manner that during inspiration it shuts off all connection with the external air and allows the air from the breathing chamber to pass freely into the mask, while during expiration it shuts off connection with the breathing chamber and ensures that the expired air shall pass into the external air, thus preventing the expired carbon dioxide from penetrating into the breathing chamber. To prevent the unpleasant and interfering effects of even a slight diminution in pressure caused in the breathing chamber with its rigid walls by each inspiration, an india-rubber bag (Y), such as the ordinary india-rubber " bladder " of a football, is fixed into the container.

By the above arrangement it is possible to let pure atmospheric air, or a mixture of atmospheric air and nitrogen, pass into the breathing chamber, and accordingly to change at will the relative proportions between atmospheric air and nitrogen ; or, in other words, to change the partial pressure of oxygen at any desired rate, thus obtaining exactly the same effect as if the partial pressure of oxygen were reduced by mounting in the air, gradually arriving at a lower and lower barometric pressure.

Professor Dreyer gives the following directions for the use of the apparatus. The electric motor is started, allowing a quantity of 22 to 27 litres of atmospheric air per minute to pass through the air-meter into the breathing chamber. At this time the T-piece (Q) inserted into the exit tube (P) leading from the nitrogen cylinder should be closed by means of the screw-clip. When the bag is more or less filled, then the person on whom the experiment is going to be carried out puts on the face mask, securing it so that it fits tightly without leakage. He is now allowed to breathe pure atmospheric air for some minutes. Under these normal conditions all control examinations should be carried out, such as frequency of pulse and respiration, hæmoglobin percentage and reaction times.

The tap of the nitrogen cylinder is then opened, and by means of the controlling valve increasing amounts of nitrogen gas are allowed to pass through the nitrogen-meter. At the same time, the amount of atmospheric air passing through the air-meter is gradually diminished in such a manner that the total volume of gas passing into the breathing chamber in each unit of time remains practically the same during the whole experiment. By this procedure it is possible to reduce the partial pressure of oxygen at any rate which is desired, as, for example, the rate at which it falls when mounting in a fast or medium-fast aeroplane, and to maintain any given pressure for any period that may be required, or suddenly to decrease or increase it. To secure accurate results, it is obvious that the accuracy of the meters should be tested beforehand, and their individual error determined and allowed for in the subsequent calculation. For further control it is also advisable from time to time to make a gas analysis of a sample of the air mixture contained in the breathing chamber, or of the nitrogen used.

It is evident that if equal volumes of air and nitrogen pass through the two meters in the same unit of time, and are properly mixed, the partial pressure of oxygen in the mixture passing into the breathing chamber corresponds to an atmospheric pressure of half-normal or a barometric pressure of 380 mm.

The simplest way to calculate the barometric pressure corresponding to a given oxygen partial pressure in the mixture of air and nitrogen is to observe by means of a stop-watch the times taken by a given volume of air and nitrogen to pass through their respective meters—for instance, the number of seconds it takes for 1, 2 or 2·5 litres respectively. It is preferable to observe the time it takes for 2 or 2·5 litres to pass, because the error of experimentation becomes small or insignificant. If P represents the barometric pressure at the time of the experiment, and T_n the time it takes for a given quantity (2½ litres) of nitrogen to pass through the meter, and T_a the time it takes for the same quantity of air to pass through the meter, it will be found that if P_1 represents the barometric pressure corresponding to this mixture of atmospheric air and nitrogen, then

$$P_1 = P \times \frac{T_n}{T_n + T_a}$$

The altitude corresponding to a given barometric pressure can then be read off in metres or feet on any of the existing tables.

Example.—If it takes 18·2 seconds for 2·5 litres of nitrogen to pass through the nitrogen meter, and 10·1 seconds for 2·5 litres of air to pass through the air-meter, then $T_n = 18{\cdot}2$ and $T_a = 10{\cdot}1$; and if the barometric pressure at the time of the experiment is 745 mm., we have an oxygen partial pressure corresponding to an atmospheric pressure of

$$745 \times \frac{18{\cdot}2}{18{\cdot}2 + 10{\cdot}1} = 463$$

Therefore, the barometric pressure is equal to 463 mm., which corresponds to an altitude of 3,960 metres, or about 13,000 ft.

The Bag Method.—This method, devised by Martin Flack, is suitable for employment when apparatus such as the Dreyer or a rarefaction chamber are not available, and when a quick method of investigating " oxygen want " is required (Fig. 3).

The apparatus is readily portable and consists of a rubber mouth-piece (M) fitting over a flat metal tube, which is joined by a flexible rubber tubing to an absorbent cartridge for carbon dioxide (C), which in turn is attached to a bag (B) of about 5 litres capacity. Just below the cartridge is a by-pass tube (*b*), through which the contents of the bag may be sampled.

Method of Use.—The subject is given the bag empty, is asked to adjust the mouth-piece comfortably in the mouth, and then to inspire deeply through the nose and blow several times into the bag to fill it. When the bag is just filled to distension a clip is placed on the subject's nose, and he is asked to breathe quietly in and out of the bag until he feels he can go on no longer. At this point he expires as deeply as possible into the bag ; the flexible tubing is clamped, and a sample of the contents taken by means of a vacuum tube from the by-pass, as much air as possible being taken from the cartridge by folding the bag about the main mass of air or closing the entrance hole from the cartridge to the bag with the hand.

This sample, which represents approximately the alveolar air after inspiration and expiration, is now analyzed, and the percentage of oxygen in the bag determined. The time of the experiment is taken, also the time at which the breathing deepens appreciably, the rate of the pulse, and any other symptom, such as blueness of lips, circumoral pallor and sweating, are noted. After the experiment a brief account is taken of the subject's experience. From his statements and the symptoms observed, an estimate can be formed as to whether the subject suffers from " oxygen want."

The experiments with normal pilots show that, in general, the normal pilot will breathe the bag from three and a half to four minutes or more, and until the percentage of oxygen falls to 8 per cent. or under.

The calculation is made as follows. Taking 16 per cent. of oxygen as the content of the alveolar air on the full vital capacity of 760 mm. Hg which is the average of many estimations, then by simple proportion the number of mm. Hg corresponding to the percentage of oxygen can be calculated. Thus, supposing the bag content is 11·5 per cent., then

$$\frac{760 \times 11 \cdot 5}{16} = 546 \text{ mm. Hg} = 9{,}000 \text{ ft. (approx.)}.$$

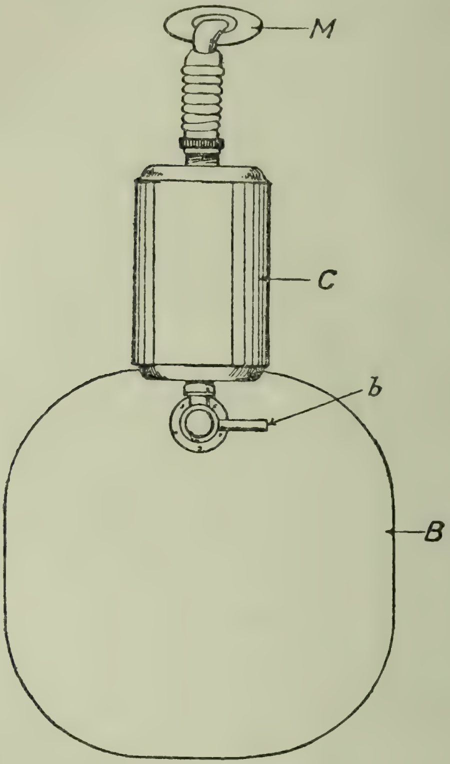

Fig. 3.—Bag method.

With the bag method a person of good physique and capable of withstanding altitude will persist for from three to three and a half minutes, and an analysis of the air remaining usually gives 6 to 7 per cent. oxygen, corresponding to an altitude of 20,000 to 25,000 ft.

The pulse rate should show a steady rise from the start. At the end it should reach about 100 per minute and should not exceed 120. When the bag is removed, it should at once fall, and should, according to Corbett and Bazett, resume its normal rate in about five minutes.

Some results obtained by this method may be seen in Table VI. In many cases the agreement with the aviator's experience is striking, but in some cases allowance has to be made for the fact that the subject does not give up at the beginning of the unpleasant stage. Care must be taken to see that the carbon dioxide in the air of the bag does not exceed ·2 per cent., otherwise the results are fallacious.

The results are, however, sufficiently near, since the chief object of the bag experiment is to confirm in a fairly quick manner the pilot's statement, and his future flying will be confined to several thousand feet below that at which symptoms develop.

It is to be borne in mind that this method is only of value for relatively approximate work, and that for accurate work, when time permits, the nitrogen method is to be preferred.

Working with the bag method, Lieut.-Colonel C. D. H. Corbett and Captain H. C. Bazett found the following abnormal responses in subjects incapable of withstanding oxygen want.

Failure may occur as the result of cardio-vascular collapse. This type may faint and suffer subsequently from dizziness and headache. The changes in pulse rate vary according to the type of case.

In cases who are physically incapable of withstanding altitude and may have done little flying the pulse rate rises rapidly and may become uncountable ; syncope may occur early.

In others syncope may also occur at a comparatively low altitude, but without an excessive rise of pulse rate.

In cases due to exhaustion who have done a great deal of flying, with perhaps a history of fainting in the air, the pulse rate may rise during the first half minute and then remain stationary or gradually fall below its rate at the start. As soon as the bag is removed the rate rises.

In another type, the oxygen consumption is abnormally rapid, leading to failure in under three minutes at an "altitude" reached by a good type in three to three and a half minutes.

Where respiration was recorded it was found that in all cases the depth was at first increased. In good types, the rate was decreased and the increased depth maintained. In bad types the breathing became shallow towards the end of the experiment, the rate being stationary or slightly raised, periodic breathing occurring when the bag was removed.

Blood concentration was observed to occur in some cases, but it was a very transitory phenomenon. It was found within two minutes of the removal of the bag, and had disappeared four or five minutes later. The maximum concentration seen was under 5 per cent. No conclusions could be drawn from the results obtained as to its value from the point of view of diagnosis.

Corbett and Bazett also made a very valuable series of observations by the Dreyer method on the reaction of pilots and observers to "oxygen want." The normal reaction to "oxygen want," corresponding to about 18,000 ft., is an increase of about 30 per cent. in pulse rate, of about 36 per cent. in pulse pressure, and after about half-an-hour some degree of blood concentration. The pulse pressure rise is brought about mainly by a fall in diastolic pressure, while the systolic pressure in the absence of mental or physical work is only slightly raised. The respiration is slowed and deepened, increasing the ventilation about 50 per cent.

Where failure to withstand "oxygen want" occurs it may be associated with an abnormal respiratory response, excessive, subnormal or periodic, while in other cases the cardio-vascular system seems mainly at fault. In these, failure appears to be caused by a subnormal reaction, except in a few instances with a very high pulse-pressure in which the diastolic pressure appears to fall to a level so low as to be harmful. It was doubtful whether blood concentration occurs in cases liable to failure.

The symptoms from which a patient has suffered when actually in the air may be reproduced by the Dreyer method, but it is most important to realize that a patient who claims to be perfectly fit at high altitudes may in reality be quite inefficient; sleepiness is the most common symptom and yet is often not recognized by the airman. It was also found that symptoms of "oxygen want" even occur in rare cases at altitudes below 10,000 ft., although the individual may appear perfectly healthy.

The Psychological Examination of the Aviator.

In allied countries the flying candidate and the flying officer were submitted to examination by various tests, such as the psychomotor responses to visual, auditory and tactile stimuli.

British experience has shown that a history of special aptitude at various sports requiring eye and hand co-ordination, as well as physical stamina, is of equal value with the results of these somewhat elaborate experiments, carried out on a special occasion, and frequently in circumstances somewhat trying to the subject.

This does not mean that the value of such tests is not appreciated and has not been investigated by the British ; it is mentioned to explain why such tests have not been adopted for routine use at the admission of candidates. Lieutenant L. Stamm investigated the value of " choice reactions " in assessing the temperament of aviation pupils at aerodromes. He demonstrated that these were of considerable value for this purpose.

Dr. W. H. R. Rivers, in conjunction with Squadron Leader T. S. Rippon, formed the opinion that a private conversation was the best means of assessing the mental aptitude of a subject for flying. They found also that the value of such assessment was greatly enhanced by comparing the opinion formed at such an interview with that arrived at by an experienced flying officer who had also conversed privately with the candidate.

In making the assessment, therefore, at a candidate's admission to the Royal Air Force it was realized that much can be gathered in the ordinary course of conversation from the way in which questions are grasped and answered, and from the way in which directions are obeyed. The resolution displayed and the method of performance of the tests for physical efficiency, for example, afforded valuable information as to the subject's mentality. Concentration on such topics as games, favourite pursuits, hobbies, interest in flying, and reasons for wishing to join the R.A.F., gave valuable indications of a temperament and mentality adapted to military aviation.

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CHAPTER VI.

OXYGEN ADMINISTRATION AND OXYGEN APPARATUS IN AVIATION.

THE chief reason for the administration of oxygen to aviators lies in the fact that the symptoms suffered from at high altitudes may in the main be attributed to " oxygen want." Although certain authorities have inclined to attribute some mechanical effect upon the body to the reduction of physical pressure, this is only of importance in connection with the air enclosed within the tympanic cavity and to a lesser extent with the gas within the intestines. Changes of absolute pressure of the atmosphere produce no mechanical effects since the altered pressure is transmitted equally in all directions through the semi-fluid body tissues. This has been proved by experiments in rarefaction chambers in which the surrounding pressure is reduced and in compression chambers in which the pressure is increased. The experience of deep sea diving also confirms the view that the body suffers no ill-effects mechanically from alterations of the surrounding air pressure, since a diver may reach a pressure of 80 lb. per square inch in less than two minutes without suffering any ill-effects other, perhaps, than some discomfort in connection with the ears.

The first definite experimental proof that altitude symptoms were due to oxygen want was brought forward by Paul Bert in 1878 and has since been confirmed by other observers, H. von Schrötter, Haldane and his co-workers, Zuntz, Loewy, and others.

To consider certain effects of flying in more detail there is with increasing altitude, apart from changes of temperature and other conditions, in the first place a deepening of the respiration in order to secure the oxygen necessary to maintain the bodily functions. At the same time the heart quickens, and thus is established the beginning of a " vicious circle." For an increase in the rate of heart-beat means an increase in the working time of the heart as shown by the following figures :—

Pulse frequency per minute.	Ratio of systole to cardiac cycle.	Hours of work, in cardiac systole per day.
50	·31	7·5
70	·37	8·9
100	·45	10·8

This increased work entails an increased oxygen consumption, the supply of which is diminishing ; thus each factor reacts unfavourably upon the other.

It has also been shown experimentally by Rohde and by Barcroft and Dixon that the usage of oxygen by the heart corresponds to the rate and maximal pressure of the pulse and with increasing height the arterial pressure is generally increased.

All the devices to render the respiration and circulation efficient will, therefore, be called into play to meet the varying conditions, so that with prolonged strain a breakdown of the respiratory cardiomotor and vasomotor control mechanisms is to be anticipated. Effective respiration is also hampered in many cases by the positive pressure of the slip-stream of the propeller and the contrary wind induced by the speed of the machine which may produce so great a positive pressure as to impede effective expiration. The fixed position of the pilot in the machine is such also that but little help can be rendered to the circulation by the pumping action of muscle movement, and even allowing for the relief given through the respiratory mechanism this is liable to become fatigued, and the circulatory mechanism must in the end suffer.

The possibility, too, of ill-effects due to the washing out of carbon dioxide from the blood by the increasing depth of breathing must be borne in mind. It is a well-established fact that deep breathing in itself gives rise to symptoms of marked discomfort, which frequently approach a sensation of giddiness.

As regards the effect of oxygen on the nervous system in preventing fatigue, it has been shown by Martin Flack, in conjunction with Leonard Hill, that oxygen greatly improves the condition of athletes. If administered before a short period of exertion, such as a run of 100 yards, it may improve the time of the performance, and certainly alleviates the distress of it ; if given at intervals during a performance, such as boxing, it greatly diminishes the distress caused by the previous performance, improves the form for the next round, and increases the staying power of the combatant. If administered after a period of long work, such as a three-mile race, it decreases the subsequent symptoms of fatigue and the runner will suffer little or no " stiffness " or other after-effects. By the administration of oxygen Martin Flack was able to restore a delirious cross-channel swimmer to consciousness, brace him to renewed effort, enable him to surpass any previous performance, and almost to achieve his end.

Briefly stated, it has been shown that the administration of oxygen to men undergoing severe physical effort at sea-level or ordinary altitudes :—

(1) tends to keep an efficient slow pulse ;
(2) tends to keep up a good arterial pressure and to delay the onset of arterial hypotension ;
(3) keeps off the onset of hyperpnœa or dyspnœa ;
(4) mitigates any ill-effect due to excessive deep breathing ;
(5) increases the power for nervous concentration and muscular work.

While testing the first apparatus for use in the war, Martin Flack in conjunction with Lieut.-Colonel C. B. Heald made some observations upon the value of the administration of oxygen in flights at low altitudes.

It was found that a short flight without oxygen appears to have little effect upon an experienced normal pilot. If he has "stunted" at all he may have acceleration of the pulse, an increase in arterial pressure, a diminished power to hold the breath, and some nervous exhaustion as shown by the McDougall machine for testing nervous fatigue.

To pilots, in whom the strain of flying is greater, there results an arterial hypotension analogous to that of prolonged exercise. The administration of oxygen has a beneficial effect, the subject even when of an excitable nature, landing with a slow, full pulse, a normal or raised arterial pressure, and an increased power to hold the breath.

The results with the dotting machine indicate an all-round improvement with the administration of oxygen.

The best experimental evidence of the beneficial effects of the use of oxygen, however, was furnished by the improved results in the work done after the introduction of oxygen in squadrons overseas.

The Amount of Oxygen given and Method of Administration.

The percentage of oxygen in the atmosphere remains constant at 20·93 per cent. irrespective of the altitude ; consequently the partial pressure of oxgyen is proportional to the height at which the barometer stands. The relationship between height and pressure is seen in Chart I. Thus at sea-level the partial pressure of oxygen in the atmosphere is approximately one-fifth of 760 mm., or 152 mm. Hg, whereas at 20,000 ft. it is one-fifth of 360 mm., or 72 mm. Hg. Physiologically, it is the partial

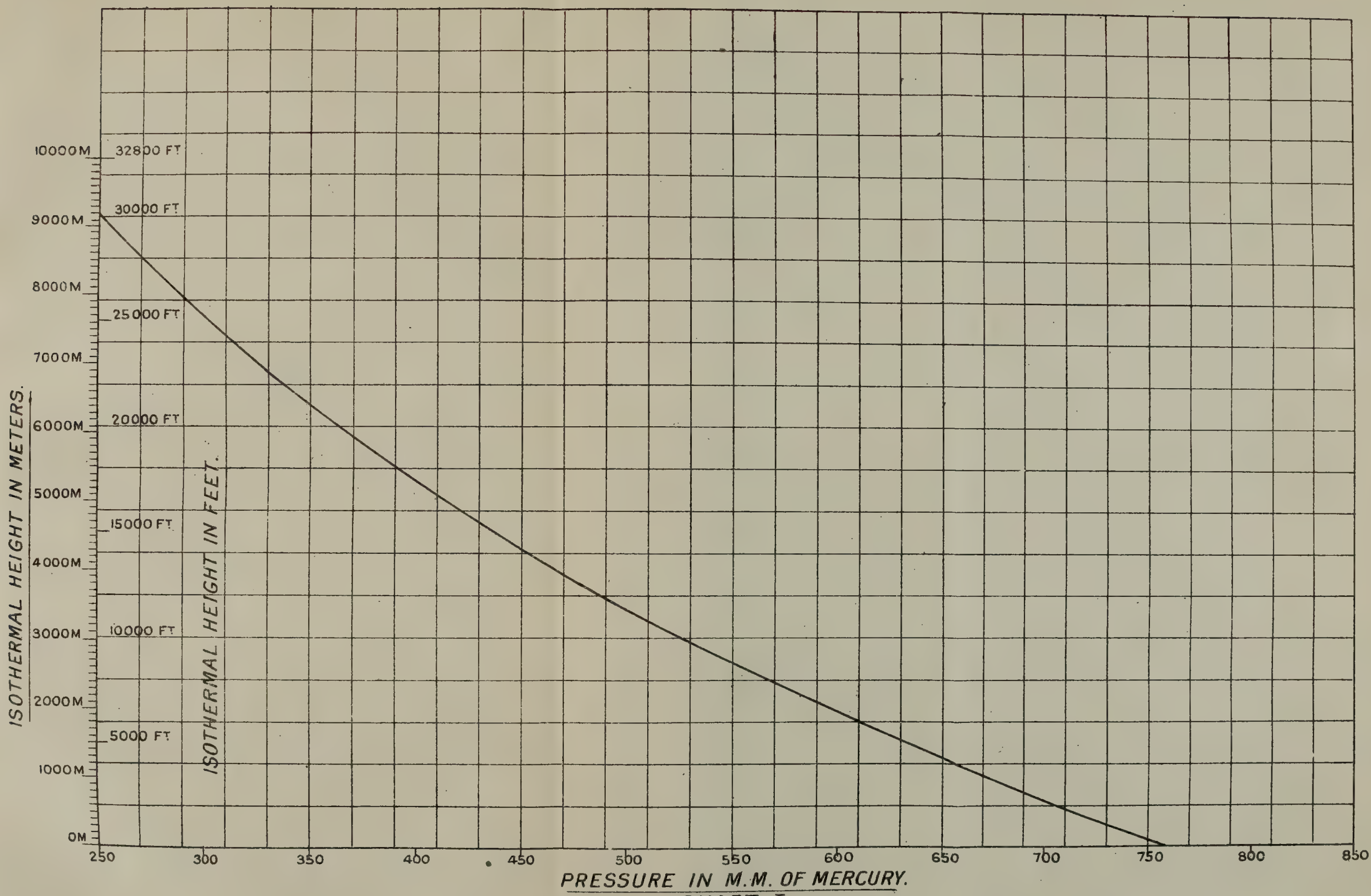

CHART I.

RELATION BETWEEN ISOTHERMAL HEIGHT AND PRESSURE.

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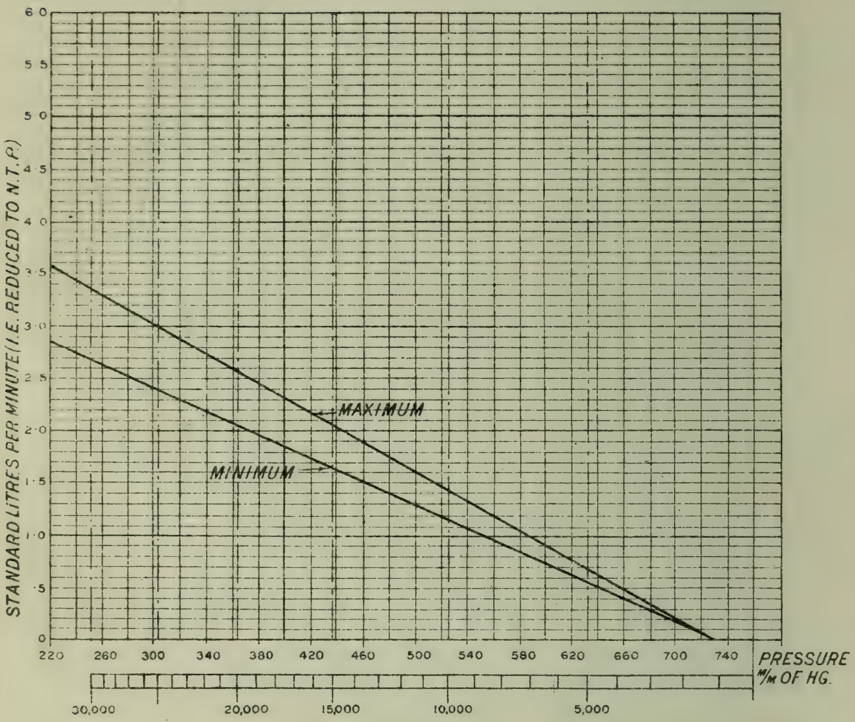

CHART II.

HIGH PRESSURE OXYGEN INSTALLATION. DIAGRAM SHOWING MAXIMUM AND MINIMUM DELIVERIES PER MAN IN LITRES PER MINUTE.

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Malby & Sons, Lith.

pressure of oxygen in the lung alveoli which is important to the aviator, and it is necessary to keep this from falling to a point at which undesirable symptoms become manifest, due allowance being made for the fact that the alveolar air is saturated with water vapour.

For the efficient administration of oxygen it is best that a mask be worn. Administration by pipe leads to dryness of the mouth and throat. After discussion as to the merits and demerits of continuous and of intermittent administration it was decided that it was preferable to give oxygen continuously from a relatively low level rather than to use it intermittently at various altitudes when deemed necessary. The amount of oxygen recommended for various heights is seen in Chart II.

Oxygen Apparatus.

The standard oxygen apparatus of commerce was far from satisfactory for aviation usage.

The cylinders were very heavy and bulky, and their valves were not constructed to work satisfactorily at the varying temperatures encountered on flying at different altitudes. The reducing valves were very heavy and cumbersome and their delivery was affected both by the lowered barometric pressure and by the reduced temperature. The breathing bag ceased to be flexible at low temperatures, and the masks were quite unsuited for use on aeroplanes on account of the tendency of the valves to freeze up during use and by reason of their general bulkiness.

It became necessary, therefore, to evolve entirely new patterns of all the units of an oxygen equipment. The essential features governing the design were held to be as follows :—

Cylinders.—These must be as light as possible consistent with safety, must be capable of quick attachment to machines, and must be capable of withstanding working pressures up to 150 atmospheres.

Valves.—The cylinder valves must remain gas-tight when either fully closed or fully opened, and must be easily operated.

High-pressure connections and fittings must be capable of withstanding the full pressure of oxygen and be easily manipulated ; the tubing must be sufficiently pliable to be adapted for attachment to any machine.

The high-pressure oxygen regulators must be of light construction, operated either automatically in accordance with the aviator's oxygen requirements at varying altitudes, or, alternatively, with the minimum of hand adjustment; they must be unaffected by low temperature, and should preferably embody a flow indicator.

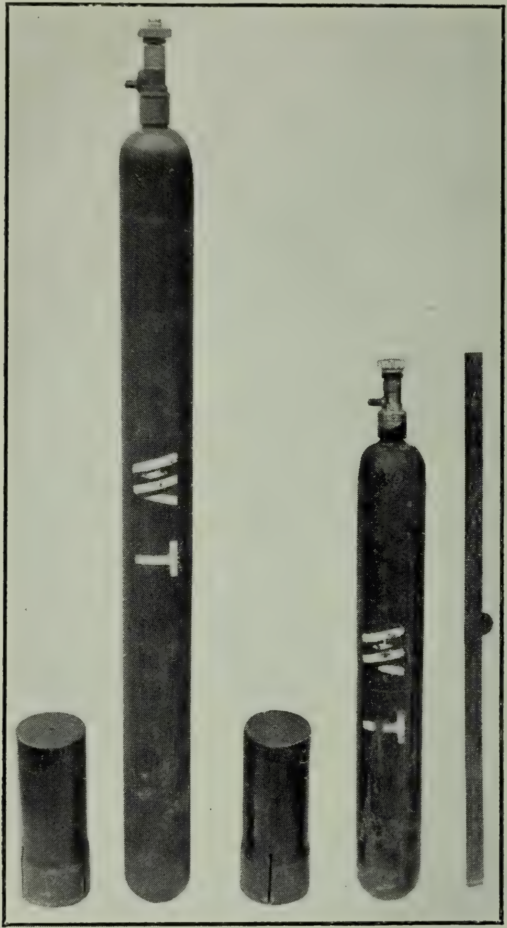

Fig. 1.—(Left) Mark IIA cylinder. (Right) Mark IIB cylinder.

The oxygen mask must obstruct the aviator's vision as little as possible, must be so constructed as to fit the varying contour of different aviator's faces, and must provide for breathing through both mouth and nose; its working also must be unaffected by low temperatures.

High-pressure Oxygen Cylinders.—The original small cylinder issued to the Royal Air Force for use on aeroplanes had a capacity of 10 cub. ft. (284 litres) at a pressure of 120 atmospheres, and weighed, complete with valve, 14 lb. This was superseded by a special design of cylinder, due in a large measure to the efforts of Lieut.-Commander Wylie, made in two sizes (Marks IIA and IIB). By the use of high-grade steel and a special process of strain hardening or tempering the weight of these cylinders was greatly reduced and the working pressure was increased to 150 atmospheres.

The Mark IIA cylinder has a capacity of 500 litres and weighs 6¾ lb. The Mark IIB cylinder has a capacity of 300 litres and weighs 4 lb. (Fig. 1.)

It may be pointed out that these special cylinders were designed solely for aeroplane use during the war. They did not comply with Home Office recommendations for commercial oxygen cylinders, and have only been continued for use on aircraft in peace time pending the production of a safer type of cylinder or the introduction of liquid oxygen apparatus.

High-pressure Oxygen Cylinder Valves.—Considerable trouble was experienced with the ordinary high-pressure oxygen valves of commerce, and special valves for use on aircraft were designed. These valves are a development of the original "Titan" valve, are of very light construction, and are absolutely free from leaks at a pressure of 150 atmospheres in either the fully open or fully closed position.

The High-pressure Connections and Fittings are used to convey oxygen gas from the high-pressure cylinders to the oxygen-delivery regulator; the three- and four-way connecting pieces are used to enable two or three cylinders to be coupled to one regulator for long-distance flights.

The tubing is of seamless copper, the thickness of wall being 21 standard wire gauge; it is capable of withstanding a pressure of 225 atmospheres, and is sufficiently flexible to be capable of bending round small diameters without kinking or fracturing.

High-pressure Oxgyen Regulators.—The provision of an adequate high-pressure regulator presented the greatest difficulty. The original regulator used was an adaptation of the standard "Endurance" pattern regulator, but was very far from satisfactory owing to the delivery being seriously affected by reduced barometric pressure and low temperature. It was also heavy and cumbersome, its weight being 4 lb.

A new pattern of regulator was designed by Lieut.-Colonel G. Dreyer in 1917, which was entirely automatic in action, was considerably lighter, and was practically unaffected by temperature variations (Fig. 2).

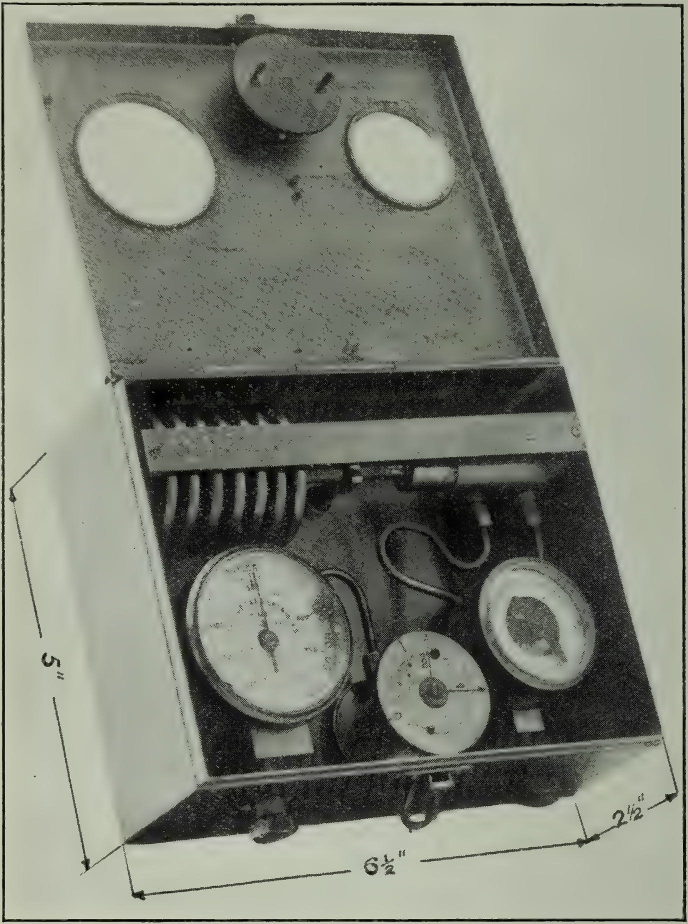

Fig. 2.—Dreyer Mark I automatic oxygen regulator, open.

Excellent reports of the efficiency of this regulator were received from the R.F.C. in the field, but as the original design of instrument required men of exceptionally high skill for its manufacture, and difficulties in production arose, it was decided to concentrate on a simple form of the apparatus in which the automatic control of the delivery was eliminated.

The Mark II regulator embodies the essential features of the original Dreyer regulator Mark I, but the control valve on the low-pressure side of the reducing valve is operated by a hand-controlled wheel in the place of the original pile of aneroid boxes; the instrument embodies a flow indicator consisting of a turbine to which is secured a finger set over a white dial; the indicator does not provide a measure of the mass delivery of oxygen (Fig. 3).

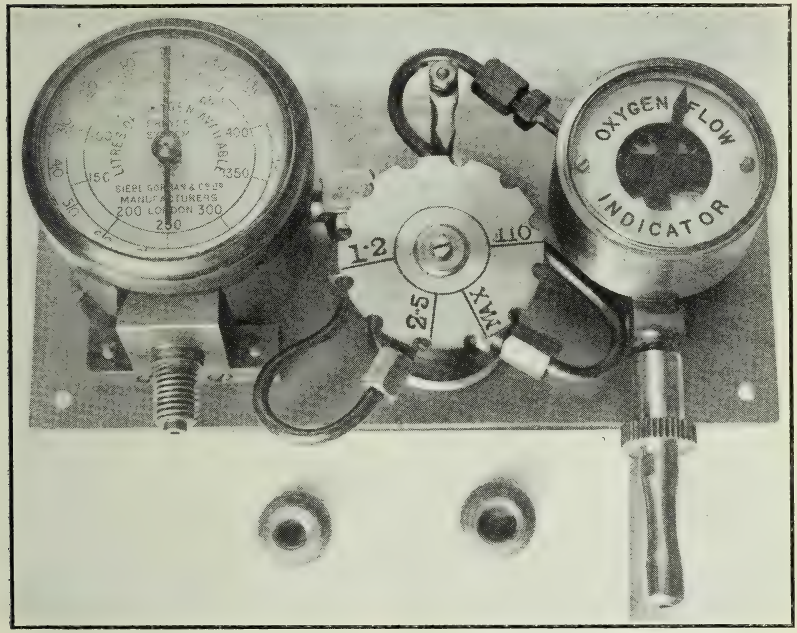

Fig. 3.—Dreyer Mark II oxygen regulator.

A Mark IV regulator (Davis's) was also developed by Messrs. Siebe, Gorman & Co. from the standard "Endurance" pattern regulator; in its construction the special requirements of a regulator for use on aircraft were taken into consideration, the faults of the original pattern were eliminated, and special attention was given to making the instrument easy of production. The delivery valve is hand-controlled, and an indicator of the volume of oxygen is provided consisting of a float moving in a glass tube with a conical bore (Fig. 4).

Oxygen Masks.—The mask originally used on aircraft was a simple adaptation of the mask used for the medical administration of oxygen. Valves of mica were used to direct the movement of inhaled and exhaled air and the delivery

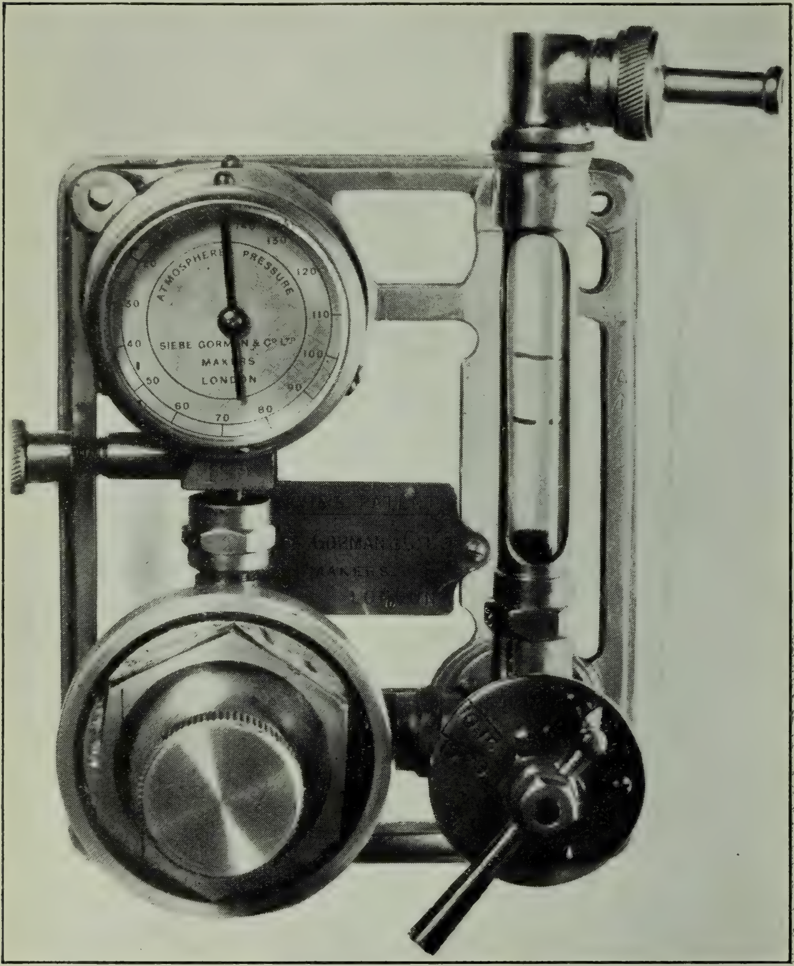

Fig. 4.—Davis's oxygen regulator.

of oxygen, and a bag of rubberised fabric formed a reservoir between the oxygen supply and the mask. The mask was of a rigid type, and a pneumatic cushion assisted in keeping it pressed against the face. In flying at high altitudes, however, the low temperatures caused the mica valves to freeze, and rendered the fabric bag stiff and useless, while the reduced barometric pressure resulted in expansion of the air in the pneumatic cushion and consequent unpleasant tightness against the face.

This mask was replaced by the Dreyer Mark I mask, which was a distinct improvement on the original mask, though economy of oxygen supply to the aviator was sacrificed by eliminating all valves, so that the oxygen flowing from the regulator during periods of expiration was wasted. The mask itself was formed of rubberized fabric, and was edged with chenille or velvet. A small hemispherical aluminium cup formed the apex of the mask, and was provided with louvres for the admission and exhalation of air. The consequent lack of rigidity led to obstruction of the pilot's vision in the event of the mask being displaced.

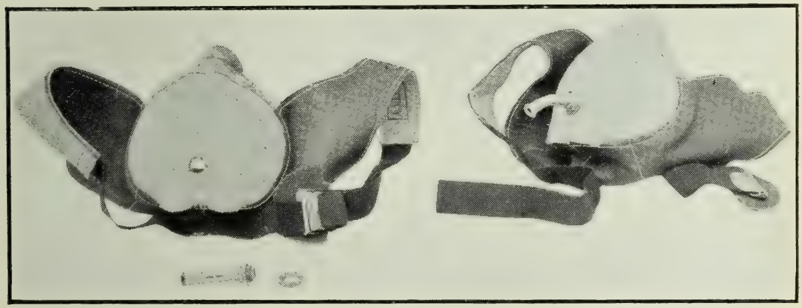

Fig. 5.—Mark II oxygen mask.

The Mark II mask, which eventually came more or less into general use, was evolved by Martin Flack in conjunction with Messrs. Siebe, Gorman & Co. This mask consists of a flexible copper dome covered inside by chamois leather, which prevents the condensation of moisture, and provided with louvres for the admission and exhalation of air, the louvres being so arranged that expiration is not impeded by the force of the slip-stream or of the wind. The edge of the dome is suitably padded, and the copper is sufficiently flexible to be moulded to the face of the wearer; broad straps lined with chamois leather give adequate protection to the cheeks against frostbite (Fig. 5).

A Mark III pattern of mask was evolved early in 1918 to meet the requirements of pilots and observers who wished to take oxygen intermittently and to abandon the mask at

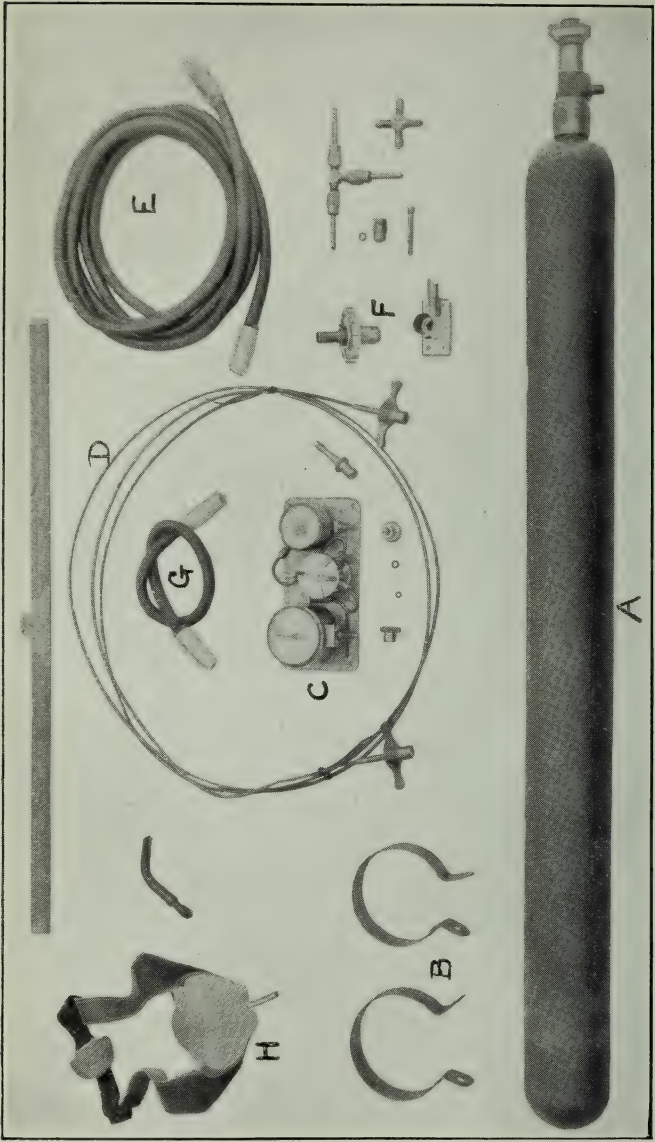

Fig. 6.—Complete outfit of compressed oxygen apparatus. A, cylinder; B, cylinder clips; C, regulator (Mark II); D, high-pressure tubing; E, flexible tubing from regulator to bayonet union; F, bayonet union; G, flexible tubing, bayonet union to mask; H, mask (Mark II); I, three- and four-way connectors. (Scale by comparison with two-foot rule shown at top.)

will, as, for example, when actually engaged in fighting. The mask consists of the same flexible copper dome as used in the Mark II mask, but has no straps for fastening, the edges of the copper dome being suitably padded with " Selvyt " material. An extension of the oxygen supply pipe, consisting of a vulcanite pipe-stem, enabled the mask to be held by the teeth over the mouth and nose of the wearer, and breathing could be carried on through both mouth and nose. There are three positions in which the oxygen supply pipe can be placed, and the mask can be held in position with the pipe-stem held by the teeth in the centre of the mouth or on either side.

A bayonet union was designed to enable an observer to detach himself instantly from his oxygen supply, and to provide a rapid means of re-connecting. The union consisted of a female base-piece for attachment to the aeroplane, and male fitting to which the flexible tubing to the mask is connected. The union was made of duralumin throughout, with the exception of the two bronze connectors and two steel grub screws.

Fig. 6 shows a complete compressed oxygen installation for " Scout " machines.

Liquid Oxygen Apparatus.—The considerable development which has taken place during recent years in the production of liquid oxygen rendered it possible to adopt liquid oxygen in the place of compressed oxygen for many purposes. This was particularly the case in Germany, and it was discovered from machines shot down that liquid oxygen was being used by the Germans for aviation purposes. Liquid oxygen has certain advantages over compressed gaseous oxygen for use on aircraft :—

1. It can be stored at atmospheric pressures.
2. It is safer to use under rifle or shell fire.
3. It vaporizes more readily, as the atmospheric pressure is reduced, thus tending to give automatic increase of delivery with altitude.
4. The regulation of rate of supply is simplified, since the pressure in the container is constant.
5. The containers are very much lighter than high-pressure oxygen cylinders for equivalent capacity.

Against these advantages the use of liquid oxygen entails certain disadvantages :—

1. It can be satisfactorily stored only in vessels insulated by very high vacua or effective lagging.

(2) Even with the best type of storage vessels there is constant small loss by evaporation.

(3) Installations must in all cases be charged with oxygen immediately before a flight, since the liquid can be kept only for a limited period.

Following a certain amount of research work, experimental orders for liquid oxygen equipment were placed in the summer of 1918, and a very considerable development of the research work took place. The equipment of the R.A.F. with liquid oxygen installations, to the exclusion of compressed oxygen outfits, has now been definitely recommended. At the time of the armistice long-distance bombers were being equipped in this manner.

Research work on the many problems presented by the requirements of liquid oxygen installations proceeded side by side with the production by manufacturers of liquid oxygen containers, vaporizers, control fittings and flow meters. It was early realized that the successful adoption of liquid oxygen installations depended in great measure upon the production of the requisite quantity of liquid oxygen at places not too far removed from the place of usage, and early in 1918 orders were placed for a number of liquid oxygen-producing plants of a portable type.

Production of Liquid Oxygen Vessels.—Prior to the war no metal vessels for holding liquid air or liquid oxygen had been produced in the United Kingdom. Designs of vessels were prepared in the summer of 1918, and by the end of the year a number of successful containers and vaporizers had been made, tested and found satisfactory. Sir James Dewar afforded much valuable information to the Air Ministry in the early stages of the work. Containers were used for transporting and storing the liquid oxygen required for use in liquid oxygen installations. The standard Air Ministry container (Fig. 7) has a capacity of 20 litres of liquid oxygen when filled to four-fifths of its full capacity.

The complete container consists of a vacuum-jacketed metal vessel provided with a sealing-off tube, with protective cap, and a receptacle for holding charcoal. In the pattern used during the war, the vacuum space was exhausted to a pressure of $\frac{1}{1000}$th of a millimetre of mercury before sealing off, and the loss by evaporation in approved containers did not exceed 5 per cent. of the amount of liquid oxygen per twenty-four hours. The weight of a container complete was 32 lb.

The construction of vaporizer vessels follows in general principle that of containers. They were made in three sizes, with nominal capacities of 1, 3 and $4\frac{1}{2}$ litres respectively. The loss by weight of liquid oxygen in approved vaporizer vessels did not exceed 1 lb. per five hours (*i.e.*, approximately 1 litre of gaseous oxygen per minute).

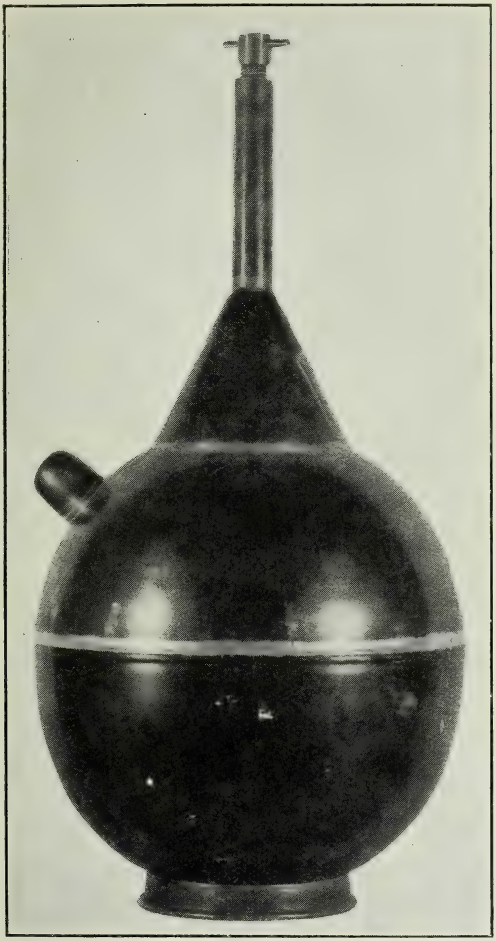

Fig. 7.—Twenty-litre liquid oxygen container.

The vaporizing chamber consists of an annular vessel surrounding the neck of the bottle; the base of the chamber carries a series of blind pendant tubes which provide additional heating surface; the heating coils of drawn copper tube are completely arranged above the vaporizing chamber (Fig. 8). By the inflow of heat liquid oxygen is forced by the siphon tube (S) to the flash boilers (F), where it evaporates and is conducted to the delivery apparatus by tube (D).

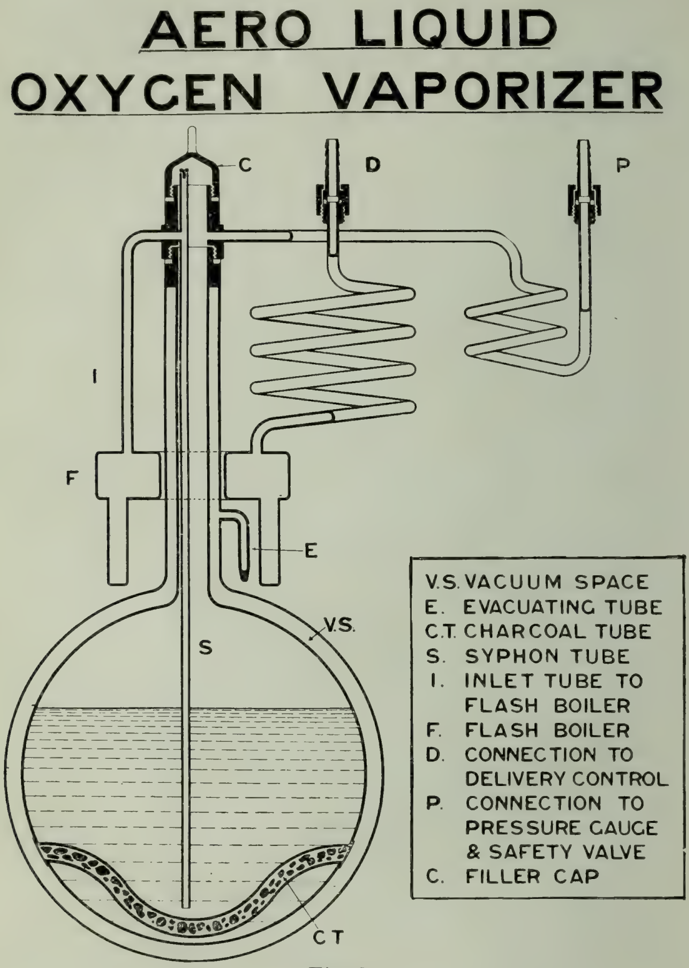

Fig. 8.

Control fittings are used to control the supply of oxygen gas from liquid oxygen vaporizers to pilots and passengers on aircraft. The R.A.F. pattern of control fitting comprises essentially a control valve of the screw-down needle type operated by a hand-wheel, and a pressure release valve of conical form closed by a spiral spring, the compression of the spring being adjusted by a threaded sleeve screwed into the body of the fitting; the pressure release valve is kept adjusted to blow off at 15 lb. per square inch. The weight of the control fitting, complete with pressure gauge, is $1\frac{1}{4}$ lb.

Flow meters are used to indicate the volume of delivery of oxygen gas from liquid oxygen vaporizers and control fittings. The indication is obtained by the oxygen gas passing through a special jet and impinging on a hinged vane which is deflected against the action of a spiral spring; the vane carries a pointer which traverses a dial calibrated in white figures to read from 0 to 6 litres per minute.

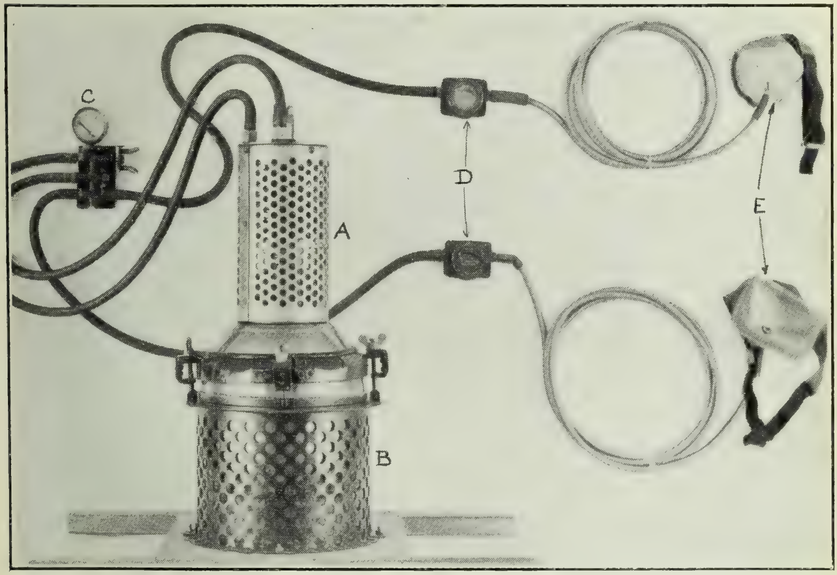

Fig. 9.—Liquid oxygen delivery apparatus for two men. A, liquid oxygen vaporizer; B, holder in which vaporizer is carried; C, control fitting; D, flow meters; E, breathing masks (Mark II).

Fig. 9 shows a complete liquid oxygen installation for two men.

A number of German liquid oxygen outfits were taken from captured enemy aircraft during the war, and numerous examples were examined. In all cases the vaporizer bottles showed excellent workmanship, and were of high efficiency, but all other parts of the installation were far below British standards. In no case was any attempt made to utilize the gaseous oxygen escaping past the pressure release valve, and a considerable proportion of the oxygen carried was therefore wasted by dissipation into the atmosphere without passing into the mask.

Fabric breathing-bags were used in all cases, the bag being protected by an outer bag of coarse " canvas " made of paper fibre—the same material as was used so largely by the enemy for sand-bags and for helmet covers. The oxygen supply pipes were of very low-grade rubber, with a plaited outer covering of fibrous material.

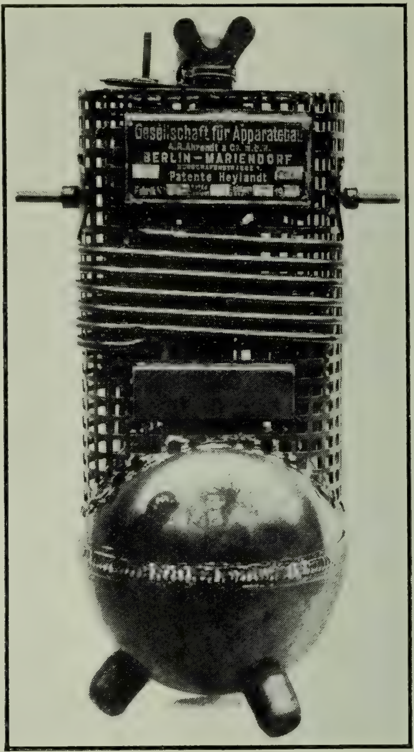

Fig. 10.—German liquid oxygen vaporizer, captured in the summer of 1917.

No oxygen face-masks were found, the oxygen supply pipes in all cases terminating in a " bend " of a bone-like material resembling some of the common milk products ; in some cases detachable wooden pipe stems were made to fit into these bends, and in other cases the bends were fashioned to be held direct between the teeth.

It would appear that the oxygen was only intended to be used intermittently. Fig. 10 illustrates a sample of liquid oxygen apparatus taken from enemy aircraft captured in the summer of 1917.

Practical Experience of Oxygen Apparatus.

The probability that an artificial supply of oxygen would be necessary in order to protect flying personnel from the effects of lowered barometric pressures first became apparent in the closing weeks of the 1916 campaign. At that time the fighting scout machine was being rapidly developed, and a " ceiling " of over 20,000 ft. was confidently and correctly anticipated. No oxygen apparatus had yet been designed which was in the least fitted for aeroplane work, where not only were compactness, lightness and reliability essential, but in view of a pilot's multifarious duties automatic action was highly desirable if it could be attained without undue difficulty.

The apparatus designed by Lieut.-Colonel Dreyer, R.A.F., eventually came into use and was manufactured in Paris during 1918 under the supervision of Captain J. Freeman. It was also turned out in large quantities in America, the modified form (Dreyer Mark II) being made in the United Kingdom.

It had the great advantage of automatically supplying increasing amounts of oxygen with increasing altitudes and decreasing amounts with decreasing altitudes, and it was so regulated that the pressure of oxygen in the inspired air, *i.e.*, the pressure of atmospheric oxygen plus that artificially added, never fell below that obtaining under normal conditions at sea-level. It possessed an indicator which could be read at a glance, and required no regulation by the pilot, who was already overburdened with a multitude of instruments.

This apparatus was not the acme of perfection ; it suffered from defects of its own as well as from the drawbacks inherent to all high-pressure apparatus. As regards its own particular defects, it was not easy to manufacture ; it was hardly robust enough to withstand the rough usage of active service ; while owing to the complexity of its valves it tended to lack reliability. Nevertheless, when in good working order, it was extraordinarily well adapted for the purposes for which it was designed.

Against all high-pressure apparatus the following objections can be legitimately advanced. The first is the certainty of a serious explosion should the cylinder be pierced by a bullet; this was early recognized by the Germans. The old heavy cylinder which was used in 1917 was far less dangerous in this respect than the light one which became available in 1918, as is evidenced in the following report of some experiments carried out in France on 17th June 1918, by Captain W. R. Bruce-Clarke and Lieut.-Colonel Birley.

> " Six cylinders in all were fired at.
>
> A. English Light Cylinder, charged to a pressure of 100 atmospheres, fixed to a bomb-rail underneath the plane of an S.E.5.
>
> When hit by the bullet there was a loud explosion. One end of the bomb-rail was torn clean away from the rear main spar; the bomb-rail itself was bent, and a large hole was blown in the upper and lower surfaces of the fabric about the size of the inner bay of the lower plane. All the cross-bracing wires were strained, and the control cable passing through the plane was stretched. The two forward ribs in the inner bay were blown entirely away. Both main spars were cracked and the inner compression rib of the plane was also cracked. Two pieces of the cylinder were picked up 35 yards away and one piece 5 yards away.
>
> B. English Light Cylinder, charged to 100 atmospheres, fixed in the fuselage at the first bay behind the pilot's seat. This was wired down with strong copper wire to the first two cross-members behind the pilot's seat.
>
> On being hit, portions of both bottom longerons were entirely blown out, and also both bottom cross-members of the bay where the cylinder was fixed. In addition, the second montant behind the pilot's seat was entirely blown away; all rods in the neighbourhood were strained and several control wires broken. The top fairing of the fuselage was badly damaged, and there is no doubt whatever that the machine would have broken up had this occurred in the air.
>
> C. Heavy Type Cylinder, charged to 100 atmospheres, wired to the fuselage as in B. Cross-bracing wires in rear of the pilot's seat were strained, but otherwise there did not appear to be a great deal of damage done.
>
> D. Heavy Type Cylinder, charged to 140 atmospheres, fitted to bomb-rib on the plane.
>
> Very little damage; one rib was smashed and a small hole torn in the fabric.
>
> E. English Light Cylinder, wired as in B, but empty.
>
> When struck there was a loud report, but the cylinder remained complete, with bullet-holes of entry and exit. A small portion of fabric was blown out of the side of the fuselage, but no other damage was discovered.
>
> F. English Light Cylinder, charged to 150 atmospheres, wired as in B.
>
> When struck, the cylinder blew up with a loud report. Only three small pieces could be found, one 150 yards away and the other two 35 yards. Everything in the neighbourhood of the cylinder, with the exception of the two top longerons, was smashed to pieces."

The second drawback to high-pressure apparatus is its weight and bulk, which impose a limit on the amount of oxygen which can be carried.

The third objection lies in the number of parts of which the apparatus consists, namely, cylinder, high-pressure tubing connecting cylinder with regulator with a junction at both ends, regulator and indicator, light tubing and mask. To fit the apparatus into an aeroplane, or even to change a cylinder, takes up a considerable amount of time, and great care has to be taken that no leakage occurs at the junctions on the high-pressure side of the system.

The liquid oxygen apparatus used by the enemy was free from these defects. Early in 1918 arrangements were initiated in England to supply the expeditionary force with liquid oxygen and the necessary apparatus, and had the war gone on into 1919, the existing high-pressure apparatus would have been entirely replaced. The responsible authorities were much criticized for not insisting on liquid oxygen from the outset. It is true that the apparatus designed by Sir James Dewar, and copied by the Germans, came before the notice of the flying services in the summer of 1917, but by this time at least one squadron in France was already in grave danger of being put out of action owing to the want of an oxygen apparatus. In other words, oxygen in any shape or form was essential, and the only apparatus then available was the Siebe-Gorman pattern modified from an apparatus designed for use in mines and admittedly ill adapted for use in aeroplanes. Nevertheless, it was infinitely preferable to nothing at all and filled, however indifferently, an awkward gap until replaced by the Dreyer automatic regulator. Had the authorities of the expeditionary force insisted in 1917 on liquid oxygen to the exclusion of compressed oxygen, no apparatus would have been available in the field before the spring of 1918, and the high photographic reconnaissance carried out before and during the battles of 1917 either could not have been done at all or would have been done ineffectively and at the cost of a tremendous wastage of flying personnel from physical causes.

Moreover, the industrial position in Great Britain differed fundamentally from that of Germany, which, cut off from the nitrate supplies of South America, was forced to develop on a large scale the manufacture of liquid air in order to secure the supplies of nitrogen necessary for making explosives. Germany, therefore, had no difficulty in equipping aeroplanes with liquid air or oxygen. In order to secure a supply of liquid oxygen for the British Expeditionary Force, not only had special containers to be manufactured, but, in addition, plant for the manufacture of the liquefied gas itself would have had to be set up in France, while owing to loss from evaporation special arrangements for rapid transportation would have been necessary.

The first experiment with oxygen apparatus in France was carried out at Dunkirk on 10th December, 1916, by Major R. S. Dallas on a Sopwith triplane, the apparatus employed being that designed by Messrs. Siebe, Gorman & Co. from their mine-rescue apparatus. The following is an extract from the original report :—

> " The oxygen set adjusted to release 1 litre O_2 per minute was not used until a height of 17,500 ft. had been attained. It was then taken in breaths at intervals of about five minutes, and in fairly weak doses. Breathing oxygen appeared to relieve the pressure of breathing in the ordinary way at this height. As greater altitudes were reached, the valve was opened to a fuller extent and the result of the extra supply was noticeable in the fact that it caused drowsiness. At 26,000 ft. the valve was opened to allow 1 litre per minute to pass through. Four or five breaths of this caused the pilot to go almost to sleep, the effect being that he could see the earth and places below, but could not concentrate or think about anything."

This report had an unfortunate result in that it prejudiced the authorities against oxygen, the pilot's interpretation of the effects being accepted without further question. The experiment was not brought to the notice of Lieut.-Colonel Birley, the medical adviser of the Air Force in France, until a month later, when, after interviewing the pilot, he reported that " the officer's interpretation of the effects observed is open to the obvious and serious criticism that (*a*) an excess of oxygen in the inspired air does not cause drowsiness or mental obscuration, but rather the opposite, and (*b*) the symptoms complained of are characteristic of want of oxygen and have been noticed in previous experiments." It was, in fact, evident that the apparatus as used was not delivering to the pilot oxygen in sufficient quantities.

On 2nd March, 1917, a test was carried out with the first Dreyer distributor. The machine failed to climb above 17,000 ft., but the apparatus worked perfectly, although the mask proved unsatisfactory.

The next three months was a period of time wasted. The executive authorities in the field were barely convinced of the necessity for oxygen, and not at all of its urgency. Instead, therefore, of requesting the authorities in the United Kingdom to push forward the manufacture of the Dreyer distributor, an apparatus which, though admittedly not perfect, would at any rate have been accepted by the expeditionary force, the manufacturers were permitted to concentrate on the Siebe-Gorman apparatus, which for military purposes had drawbacks that could only be appreciated by those in the field.

During May 1917 No. 55 Squadron began to carry out high (20,000 ft.) photographic reconnaissance lasting two or three hours with single machines unescorted, and it soon became apparent that this work was being hampered by the mental and physical effects characteristic of "oxygen want." During the same month Lieut.-Colonel Birley was engaged in making experiments in the air with the Siebe-Gorman apparatus sent out from home, and also with the only two Dreyer apparatus then available. Two things became strikingly evident as a result of these experiments. In the first place, although the Dreyer apparatus was clearly more convenient for aeroplane work than the Siebe-Gorman, the latter was certainly better than nothing at all, its main drawbacks being the badly made joints on the high-pressure side with resulting tendency to leakage, and its lack of automatic action. Secondly, it became more and more obvious that an artificial supply of oxygen would benefit pilots and observers far more and at lower altitudes than had hitherto been imagined.

The following is extracted from a report on a test with the Dreyer regulator on 25th May, 1917. The flight lasted two and a quarter hours, a maximum altitude of 21,000 ft. was reached, and a height of over 15,000 ft. was maintained for eighty minutes. The report of the pilot, Flight-Commander F. Fowler, was as follows :—

> "The oxygen was turned on as we left the ground, and the apparatus not touched again until we landed. The effect of oxygen at high altitudes is extraordinary; one feels none of the usual effects of height, and one apparently has just the same amount of energy and power to handle the machine as near the ground. I am sure that a pilot fitted with this instrument would have an enormous advantage in a fight at altitudes over a pilot without one. I am also sure that pilots will be able to last much longer with oxygen and do a much greater quantity of high flying, as the effects after a sustained flight without oxygen are such that one has so little energy and feels so slack and tired, that, except in very special circumstances, it is impossible to go up again. When using oxygen none of these effects were noticed, and I felt perfectly able to go up again almost straight away. I did not feel, or do not yet feel, two and a half hours after the landing, at all tired, as I would have done under ordinary circumstances."

The immediate result of this test was a demand for the Dreyer apparatus by the Royal Naval Air Service.

In the first week in June 1917 No. 55 Squadron, which was doing all the important high photographic reconnaissance preparatory to the Messines attack, was in grave danger of being put out of action ; their flying officers were becoming rapidly exhausted by long exposures to 20,000 ft., and two instances were reported of loss of consciousness in the air. It was then recognized that oxygen was indispensable, but the necessary apparatus was not forthcoming. Twelve Siebe-Gorman sets, sent from England for experimental purposes, were hastily fitted into the machines, but owing to leakage proved far from satisfactory. This defect, however, was in great measure eliminated in succeeding consignments from home, and cylinders of 10 cub. ft. capacity were secured from a French source, which although heavy at least contained sufficient gas for prolonged flights. Thus early it had become apparent that oxygen would be required by two-seater machines rather than by fighting scouts, for which the Dreyer apparatus had been especially designed.

By October 1917 the position had improved ; the Siebe-Gorman apparatus was gradually being replaced by the Dreyer instrument manufactured in Paris, and the replacement was complete by March 1918. In addition Dreyer apparatus, Mark II, manufactured in England, became available. In this year a great improvement was marked by the introduction of a light cylinder made in England.

The great practical difficulty in the way of oxygen lay in the necessity of using a mask. This difficulty was especially felt by fighting pilots, who strongly objected to having anything over their face ; some, in fact, were in the habit of dispensing with goggles and flying helmet when fighting. The scout pilot, although attaining great heights, did not remain there long and so suffered far less from anoxæmia than the officer employed on long reconnaissance at 20,000 ft. For the latter oxygen was a routine and a blessing, and was recognized as such. In scout squadrons it never became a routine ; it was tried sporadically by numerous pilots but in nearly every case was eventually discarded, its advantages being deemed to be outweighed by the disadvantages of the mask. The substitution for the mask of a pipe held between the teeth was unsatisfactory from the medical point of view, since it encouraged intermittent, as opposed to continuous administration, while a great deal of oxygen is wasted by this method. At high altitudes, too, when the pipe was taken out of the mouth for a few minutes, the wet end rapidly became frozen.

In 1918, when the benefits of oxygen were better appreciated, its use conferred great advantages. With extra petrol accommodation machines were capable of flying at 20,000 ft. for four hours. The use of oxygen under these conditions not only rendered flying officers alert in the air, but it also materially lengthened their period of efficiency in the field. It can, in fact, be stated that this particular kind of work without oxygen is a physical impossibility.

In 1918 an attempt was made with some but nothing like complete success to encourage Bristol Fighter squadrons to use oxygen as a routine. Most Bristol Fighter pilots and observers, especially the latter, admitted to feeling the effects of high altitudes and were only too willing to take the necessary steps to counteract them. The one great difficulty consisted in arranging the method of administration of oxygen to the mouth in such a way that it would not interfere with their freedom of movement for fighting. The following memorandum, which was circulated in September 1918 to the squadrons concerned, is reproduced as an example of the propaganda employed to convince officers of the advantages of oxygen, which, like most of the wares displayed by the medical services, was regarded by many as a dope.

" 1. *The sole purpose of the employment of oxygen in the air is to increase the efficiency of pilots and observers.*

" 2. It is common knowledge that oxygen is necessary for life. It is only in the presence of oxygen that the processes of combustion can take place by which the potential energy of the food which we eat is converted into other forms of energy, viz., heat and work.

" Oxygen is carried by the blood to all parts of the body. It is taken up by the blood as it circulates through the lungs ; this is known as respiration. Moreover, the amount taken up depends on the pressure exerted by the oxygen in the air. If the pressure is diminished, less oxygen will be taken up and symptoms of 'oxygen want' will supervene.

" 3. The air consists of (approximately) 80 per cent. nitrogen and 20 per cent. oxygen. The pressure exerted by these two gases acting together is 30 in., or 760 mm. of mercury at sea-level. This is known as the atmospheric pressure. The pressure exerted by the oxygen alone is, therefore, 20 per cent., or one-fifth of 760, *i.e.*, 152 mm. Hg. It is clear that the pressure of the oxygen will be lowered either by a lowering of the atmospheric pressure or by a fall in the percentage of oxygen, while the atmospheric pressure remains unaltered.

" For example, if instead of the normal proportions at ground-level the air contains 90 per cent. nitrogen and only 10 per cent. oxygen, the pressure exerted by the latter is—

$$\frac{10}{100} \times 760 = 76 \text{ mm. Hg.}$$

" Again, at 19,000 ft., although the composition of the air is unaltered, the total (atmospheric) pressure is only half the normal. Hence the pressure exerted by the oxygen is—

$$\frac{20}{100} \times \frac{760}{2} = 76 \text{ mm. Hg.}$$

" In both cases, therefore, the pressure which drives the oxygen into the blood is only half the normal and accordingly the body will receive only half of what it is accustomed to.

"4. It may here be mentioned that many pilots and observers declare that they are perfectly fit at 19,000 ft. Now, man was built for living on the ground, and it is in the highest degree improbable that Nature would have supplied him with a given amount of oxygen if half that amount would have done just as well.

"Further, if one took a machine off the ground and landed on a mountain aerodrome at 16,000 ft., very few individuals would be able to walk more than 50 yards. This means that the reason why one feels fit at high altitudes in an aeroplane is because one is sitting comparatively still. It suggests, however, that perhaps one is not as fit as one feels.

"5. All the earlier experiments in the air were, of course, made in balloons. In 1875, three French scientists ascended to 27,500 ft. They all lost consciousness, and only one survived; they were all provided with oxygen, but were paralysed before they realized the necessity of using it. The survivor thus described his experiences:—

> 'The condition of torpor which comes over one is extraordinary. Body and mind become feeble little by little, gradually and insensibly. *There is no suffering.* On the contrary, one feels an inward joy. *There is no thought of the dangerous position;* one rises and is glad to be rising.'

The important point to notice here is the paralysing effect of want of oxygen on the brain. It is not altogether unlike that produced by alcohol; *loss of judgment is characteristic of both.*

"6. Previous to this experiment balloon ascents had been made in England. It was noticed by one investigator that at 24,000 ft., although he could see his instruments clearly, he was unable to read them. In other words, sensation was unaffected, but perception was lost. Now, *loss of perception frequently passes unnoticed by the subject;* for example, a drunk man may think he is very clever, when to the sober man, with all his faculties about him, he is in reality acting in a stupid way.

"7. In the air, officers when flying at great altitudes often complain of breathlessness, which is exaggerated by muscular exertion, *e.g.*, clearing a jamb, using a pressure pump, taking photographs, etc. This, in itself, is not of prime importance; we get short of breath when taking exercises on the ground without loss of efficiency. Another common complaint is headache, especially on landing; this, of course, is unpleasant, but not of primary importance. Loss of power is sometimes noticed, and, much more important, a *tendency to go to sleep.* But the most important condition, *which usually passes unnoticed,* is loss of judgment and perception. For example, an observer returned from a high photographic reconnaissance thoroughly pleased with himself; it was discovered later that he had taken eighteen photographs on the same plate. A pilot met three enemy aeroplanes at 19,000 ft., and waved his hand to them in spite of the protests of his observer. Officers have difficulty in finding their way at great altitudes; they can see the ground and their maps, but are sometimes unable to puzzle out where they are. For the same reason they frequently make faulty reports on landing. The difficulty of keeping formation at great altitudes is almost certainly attributable to mental and physical inertia.

"8. It is well known that scout pilots are much less affected by altitude than those who maintain great heights for any length of time. This is because everybody has a reserve of oxygen stored, so to speak, up his sleeve, and it is not until this reserve is exhausted that noticeable symptoms occur.

"9. *It has recently been demonstrated in an absolutely convincing manner that a man's efficiency as a fighting force is affected by altitude.* For example, the interval which elapses between seeing or hearing something and acting upon it (pressing a button the moment a light shows) is distinctly increased after twenty minutes at 13,000 ft., and nearly doubled after sixty minutes at 15,000 ft. Similarly, the time which elapses between sighting a target and firing a machine gun is enormously increased after sixty minutes at 15,000 ft., while the time taken to fire twenty rounds is also lengthened, but to a less extent. The subjects of these experiments were three pilots whose names are familiar; they all averred that they were as fit and as quick at 15,000 ft. as on the ground. In other words, *this slowness in getting into action was not recognized by the pilots themselves.*

" 10. All healthy individuals can fly at the heights at present attained, enduring it is true a certain amount of discomfort, without oxygen. But if the altitudes are great and the flights prolonged, loss of efficiency inevitably results, to be followed after a comparatively short period by non-effectiveness for high flying, which may prove permanent. *The use of oxygen prevents this.*

" 11. All enemy long-bombers and high photographic machines are equipped with oxygen.

" 12. The oxygen apparatus provided is so regulated that the amount of oxygen breathed from the external air plus that supplied by the apparatus are together equal to the amount available on the ground. In other words, *it keeps the pilot under normal instead of artificial conditions.* It follows that if oxygen is carried, it should be used throughout the flight, commencing directly the machine has left the ground, or just before. *It should not be reserved until the individual feels he wants it, it having been shown above that the particular effects of want of oxygen which matter most are not noticed by the individual.*

" 13. The weights of the apparatus per individual are as follows :—

(i) Scout or Bristol Fighter, 7 to 9 lb.
(ii) D.H.4, D.H.9, D.H.9a, 10 to 12 lb.

This is very small when it is remembered that the differences in the weight of different individuals may be as much as 70 to 80 lb. or more.

" 14. There are two methods of delivering oxygen, (*a*) by a mask, and (*b*) by a pipe. The former is the more satisfactory, because it ensures the whole amount of oxygen delivered reaching the lungs ; there is no danger of the tube being blocked by frozen condensation water or saliva, and it protects the face from frostbite. *Nobody likes a mask at first, but one can become accustomed to it ; in fact, many officers who habitually use oxygen always fight with the mask on.*

" The mask can easily be removed. If one removed it at 20,000 ft., one would not suddenly faint, as is sometimes supposed ; on the contrary, one would derive benefit from having kept up the normal reserve of oxygen to its proper level. *This point has been proved by actual experiment in the air.*

" Some officers prefer the combination of mask and pipe, especially observers.

" 15. It is infinitely preferable to use oxygen continuously, as opposed to intermittently.

" 16. The advantages derived from the use of oxygen at high altitudes are :—

(*a*) It keeps one alert and in a condition in which quickness of perception and action, and accuracy of judgment are preserved to the full.

(*b*) It gives one more power to control the machine and to fight one's gun, and gives one a better chance of getting in the first shot.

(*c*) It gives one the tactical advantages of height without its disadvantages.

(*d*) It helps to keep one warm.

(*e*) It abolishes the disagreeable symptoms—headache, lassitude, etc.—which are so frequently experienced after long flights at high altitudes.

(*f*) It promotes good spirits and companionship in the mess."

From the purely medical point of view there is no doubt that oxygen was too little used during the war. It is easy to demonstrate that at comparatively low altitudes, e.g., 12,000 to 14,000 ft., an individual is fitter with than without oxygen. This, however, is only one aspect of the case. A pilot can be compelled to take up an oxygen apparatus, but cannot be compelled to use it. In other words, the final decision rests with him. It may be said that there are two main factors which must be taken into account in estimating the extent to which oxygen will be used in the future. First, there is the apparatus itself; a compact and convenient apparatus which can be fitted into the machine in a few minutes, and does not readily get out of order is an essential preliminary to the more extensive use of oxygen. The second and more important and difficult question is the method of administration, *i.e.*, the means which are available for overcoming the disadvantages of a mask. The dislike of wearing something over the face when fighting for one's life is not prejudice but instinct, and constitutes one of the problems which the future has to solve.

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CHAPTER VII.

INFLUENCE OF GAS WARFARE ON THE MEDICAL SERVICES.

THE effective employment of poisonous gases or vapours as offensive weapons may fairly be regarded as an entirely new development in warfare. Incendiary missiles are, of course, of ancient date, and clouds of smoke arising from accidental or intentional conflagrations have frequently been used to advantage for the purpose of concealing movements of troops. Apart, however, from the primitive method of attempting to smoke out the enemy from his fastness, or the occasional use of such contrivances as the stink-pots of the Chinese and Malay pirates, there is little evidence of any deliberate and well-considered attempt to make use of poisonous or irritating gases before the great European war.

Within the last century suggestions have been made from time to time as to the valuable results that would accrue to the force employing such a method of warfare. Lord Dundonald, for instance, had been struck in 1811 by the potentialities of the fumes of burning sulphur, and in 1855 propounded a scheme for burning sulphur on a large scale under favourable wind conditions during the siege of Sebastopol, with a view to rendering the Malakoff and Redan works untenable.* This suggestion was, however, finally and definitely rejected on the score of its inhumanity, for it was felt that an operation of this nature would contravene the laws of civilized warfare.

This view was formally accepted at the Hague Conference of 1907, when the signatories agreed to renounce the use of projectiles the sole object of which is the diffusion of asphyxiating or harmful gases. Research into the possibilities of their offensive use and of defensive measures against them was therefore deliberately avoided by the chief signatory powers.

The rapid development of modern industrial chemistry and of mechanical science was nevertheless rendering gas warfare a practical possibility for any nation that might choose to break its pact at the Hague Convention. One need only consider the main economic uses of some of the chemical substances that figured in the war, or of their immediate precursors, in order to see the truth of this. Chlorine was made commercially in large quantities before the war, but in England it was almost entirely converted into bleaching powder. Phosgene plays an extremely important rôle in the commercial production of many of the important dye-stuffs, as well as in the synthesis of such drugs as the urethane derivatives and salol, and this side of the chemical industry had become the monopoly of Germany. Dichlor-ethyl-sulphide was prepared by the Germans in plant which had formerly served for the production of synthetic dyes. Cyanides, in the manufacture of which Great Britain held a strong position before the war, are largely used in the extraction of gold from its ores, as well as in the electro-plating industry. Stannic chloride has considerable commercial value as a mordant in the dyeing of calico.

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* See Panmure Papers, edited by Sir G. Douglas and Sir G. D. Ramsay, London, 1908.

Potentially, therefore, there was poison enough available; all that was lacking was the will to use it and the skill to adapt industrial chemistry and commercial organization to the ends of warfare. Germany, of necessity, started with a great advantage in this respect. The care with which she had fostered the great chemical industries stood her in good stead when she threw discretion to the winds, and adopted a method of warfare which had always been repugnant to men who believed in observing a code of honour in warfare.

The great chemical works in Germany, such as the Badische Anilin und Sodafabrik at Ludwigshafen, the firm of Meister, Lucius und Brüning at Höchst-am-Main, the Bayer Company at Leverkusen, and the Griesheim-Elektron Chemische Fabrik possessed unrivalled facilities for meeting the military requirements of the Great General Staff. Some of the more potent toxic substances or their precursors were produced in considerable quantity before the war in the synthetic dye and drug industries—industries which Germany had made peculiarly her own, and the plant necessary for producing these substances could readily be extended or adapted from what was already in existence. What was more, the great facilities for research and the financial support offered in the laboratories of these works and in the universities of Germany had led in the past not only to the discovery of a large number of chemical products of direct and valuable service to mankind, but also, in the course of extended investigation, to the identification of many substances of little more than theoretical interest at the time, some of which had proved to be violent poisons or irritants. When the Germans embarked on their policy of gas warfare the knowledge that had been acquired in the past was recalled to mind, and the selection of such substances as dichlor-ethyl-sulphide and the organic chlorarsines, which played so large a part in the last eighteen months of the war, was undoubtedly based upon the information which had resulted from systematic research in years gone by in the province of organic chemistry.

The problem was, however, a very different one for the Allies. The British had always held a leading place in the manufacture of acids, alkalies, and bleaching powder, but in common with the French had neglected the dye industry, and had little or no experience of the commercial production of even the precursors of the organic poisons to which reference has just been made. Phosgene was not manufactured in this country before the war.

The indignation aroused when the Germans initiated gas warfare only stimulated their opponents to face the situation with greater courage and obstinacy. Naturally, defensive measures took precedence at first, though almost at once preparations were started to retaliate in kind, for while effective defence went far towards frustrating the enemy's efforts, more than this was needed if the moral of the troops was to remain unimpaired and the confidence of the enemy in his own superiority was to be shaken. New factories had to be started, new plant designed and erected, and the intricacies of manufacturing processes mastered before there was any hope of facing the enemy on equal terms. Yet the French retaliated on the Germans with dichlor-ethyl-sulphide within twelve months of the original mustard gas bombardment at Ypres, and British supplies of this poison were beginning to be received three months later.

Some idea of the scale on which gas was used for offensive purposes during the war may be gained from the following figures given by Hartley. When the British commenced to make warfare gas there was only one plant for producing liquid chlorine in this country with a maximum output of one ton a day, Germany being much better off in this respect. By the end of 1915 the British had produced 860 tons of this gas. In 1916 the British output of warfare gas was 5,150 tons, in 1917, 18,500 tons, and in 1918 (ten months), 15,500 tons, about half of these quantities representing chlorine in liquid form, the remainder being phosgene, chloropicrin, and lachrymator substances. In 1917 Germany was making 2,000 tons of gas for shell filling and 1,000 tons of chlorine per month, representing a monthly output of one million 10·5 cm. gas shells, her technical resources ensuring a much greater output of gas than was possible at this time for the British.

Throughout the entire period of gas warfare defence and offence struggled for the mastery, for the introduction of protective respirators and other defensive measures only stimulated efforts to defeat their purpose. Some gases were used in the hopes that they would penetrate the respirator, others because it was felt that the absence of strong odour or immediate irritant properties would cause troops to under-estimate the danger and so fall victims to the insidious action of the poison. At the same time new methods of liberating the gas were developed in the hopes of increasing the chance of surprising the enemy. On the defensive side every effort had to be made to forestall all new offensive plans by appropriate extension and alteration of defensive measures. Thus it came about that both sides were forced to develop an extensive defensive and offensive organization to deal with the problem of gas warfare in all its aspects, whether at the seat of war or in the munition factories, while an additional burden was of necessity thrown on the fighting troops by frequent changes of anti-gas equipment and the repeated issue of fresh instructions as the opposing sides altered their methods of offence and defence in their efforts to gain ascendency with the new weapon. Though one must give credit to the Germans for the skill with which they made use of their resources to develop the offensive side of gas warfare and to gain a long lead in the design and production of gas shell, it may certainly be claimed that so far as defensive measures were concerned the British held the leading place, for the successive alterations of the British respirator ensured in every instance that it was ahead of the German offensive developments.

There was not very much information available before the war regarding the toxicology of poisonous gases. Manufacturing processes were so carefully conducted that fatal accidents were extremely rare, and even the milder degrees of poisoning uncommon. Apart from the meagre and not very accurate accounts in the standard works on industrial hygiene and toxicology, and brief data regarding the toxic properties of chemical substances mentioned in the larger treatises on chemistry, there were but few records of detailed investigations and only rare descriptions of serious or fatal cases of accidental poisoning from gases or fumes in the industries.

Lehmann, in a series of papers, gave the results of investigations on the toxic action of hydrochloric acid vapour and ammonia in 1886, chlorine and bromine in 1887, sulphuretted hydrogen in 1892, carbon disulphide in 1894, and sulphur dioxide in 1903. His experiments were admirably conducted, and the information he obtained of great accuracy and value.

He was mainly concerned with the problem of poisoning as it might occur in factories owing to leakage from the manufacturing plant, and while making many observations on both animals and men exposed for a considerable period to low concentrations of the gases, he pushed his investigations further in the case of animals and employed strong concentrations which enabled him to give a very clear account of the rapid and fatal development of acute pulmonary œdema caused by chlorine and bromine, and of the grosser pathological changes resulting from the action of these gases.

The poisonous properties of dichlor-ethyl-sulphide had been described in considerable detail by Victor Meyer in 1886, and he recorded the effects of this substance on animals. Poisoning by nitrous fumes had attracted much attention on the Rand and in other mining areas owing to the fact that dynamite and blasting gelatine give rise to considerable quantities of this gas if they burn instead of exploding properly, and the insidious onset of acute pulmonary œdema had been described by Macaulay and by Irvine amongst others. Poisoning by sulphuretted hydrogen had been identified by Haldane as a cause of death in men succumbing to sewer gas. Carbon monoxide was, however, the gas of which the poisonous properties had been most closely investigated by Haldane, Foster, and Glaister and Logan, for in the form of after-damp it is responsible for the great majority of deaths occurring as a result of a colliery explosion or an underground fire in a mine, and the urgent necessity of combating this danger had led to careful investigation of the physiological properties of this gas. Not a few of those who had conducted research in the field of organic chemistry had had personal acquaintance with the irritant and lachrymatory properties of some of the organic halogen compounds and with the toxic action of repeated small doses of some of the organic arsenic compounds.* In general, however, it may be said that this restricted information was not easily accessible to the ordinary student of medicine ; the great majority of medical men were profoundly ignorant of the properties of, and the symptoms produced by, poisonous gases.

Throughout the war, and especially on each occasion when the enemy introduced novel substances in chemical warfare, the medical services were handicapped by the military necessity for secrecy in discussing the nature and treatment of the casualties. The casualties came for treatment into the hands of medical officers who only slowly obtained information regarding the nature of the gases used, and this information was even less widely disseminated in England than it was in France. Consequently the treatment employed often lacked the vigorous certainty that rests on assured knowledge, and the great mass of casualties was not controlled with that ideal efficiency in respect of rapid return to duty which might have been attained if medical officers could have been better informed and less dependent for guidance on the complaints of their patients.

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* See Bibliography, La Coste.

When the medical services ceased to be responsible for the provision of defensive measures against gas, they became concerned simply with the treatment of casualties incurred, and they could only point out for the judgment of the military authorities that their success in the treatment of these casualties was bound to be proportionate to the extent to which information about the nature of the injuries caused by these poisons could be generally communicated to all medical officers.

The means adopted for collecting all possible information from clinical, pathological, physiological, and chemical sources are given in Chapter X. Reports on all *post-mortem* examinations made in France on gas casualties were furnished as a routine to the D.G.M.S., and clinical studies by special officers were continually added to the mass of secret and confidential reports. It is important to emphasize one particular branch of these various studies as a lesson from the past that may be of value for the future. Pathological work revealed the essential nature of the lesions caused by each poison. Physiological work added to this knowledge and, though all attempts to find specific antidotes, other than the defensive respirator provided by the chemists, were fruitless, yet this work did instruct medical officers in life-saving means, such as the use of oxygen and of venesection, which could be employed successfully with a small percentage of casualties that would otherwise have died. But with the great bulk of patients the question was not that of saving life but that of curing the men with the least possible loss of time and of moral, and the practical ways of doing this could only be learned by a direct clinical study of the progress right through to recovery of a fairly large group of such cases. For every new gas such clinical study had to be made afresh, and the results carefully tested in every detail by medical officers experienced in the general subject of gassing or possessed of specialists' skill in dealing with certain parts of the body, such as the eyes, that might be peculiarly affected by the gas.

The reliable clinical information obtained in this way could then be communicated to all medical officers who might be required to deal with gas casualties, and it would establish in them the confidence needed for the proper control of their patients. Indeed, in this respect the need for special clinical study of a homogeneous group of casualties from any particular gas was entirely similar to that for casualties occurring on a large scale from any other new malady, such as trench fever, for which there was no collected mass of clinical experience already established to guide methods of administrative control. When once such knowledge was secured, it became possible to formulate average times of treatment and convalescence for the chief mass of the casualties, and, in correspondence with these times, to arrange for the stations on the lines of evacuation where accommodation should be provided. Special returns of the actual disposals of such a particular group of casualties could at any time be called for, so as to check the percentage movements in evacuation of the different types and to ensure that invalidism was not being unreasonably prolonged beyond the established standard time.

Early in the war the D.G.M.S. in France summoned a committee of consulting physicians and of physiologists to draw up memoranda on gas poisoning, and printed copies of these instructions, with successive revisions, were issued to all medical officers in France in June 1915, in July 1916, and in April 1918. These pamphlets summarized all the main knowledge with regard to each form of gas poisoning and its treatment. In addition, from 1917 onwards, brief statements of supplementary information were circulated to medical units in France as early as was permissible when any new gas was brought into use by the enemy. These general methods of instruction were supplemented in the army areas by special lectures at the army schools, and to some extent by occasional lectures at the bases.

When experimental studies on gas poisoning were developed in England at the research laboratories, some difficulty was experienced at first in bringing English experimental workers into closer touch with those in France who were dealing with casualties experienced in the field. In January 1918 the D.G.A.M.S. at the War Office, in co-operation with the Chemical Warfare Department and the Medical Research Council, appointed a Chemical Warfare Medical Committee to co-ordinate and prepare for issue to medical officers concerned with the treatment of gas poisoning information based on reports received from all sources. Through it a number of useful reports was printed and issued to specialist medical officers in England and in France embodying the researches of the Porton Physiological Staff and other special clinical investigations in England. The main pathological changes caused by the different warfare gases were illustrated in an Atlas of Gas Poisoning published in August 1918.

From 1916 onwards a very close liaison was maintained in France between the French and the British gas services. Reports were unreservedly communicated to each other, and inter-allied gas conferences were held in Paris at which all possible information on every aspect of the subject was confidentially placed before the representatives of each of the allied armies. Officers from the British medical service attended as well as those from the services more directly concerned with chemical warfare, and so had the advantage of comparing the French methods of treatment and organization with the progressive changes in the British methods. Very complete machinery thus existed for the instruction of the Americans in actual experiences of gas warfare when their representatives joined these conferences.

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CHAPTER VIII.

CHARACTERISTICS, CLASSIFICATION, AND METHODS OF EMPLOYMENT OF POISONOUS GASES.

UNDER the heading of "warfare" or "battle" gas (German "Kampfgas," French "gaz de combat") are included those poisonous gases, liquids, or even solids which were intentionally dispersed in the air by one means or another with a view to killing or incapacitating troops of the opposing side. It will, however, be convenient to refer, in addition, to the action of certain other poisonous gases, the occurrence of which during active warfare may be regarded as accidental rather than intentional, and to artificial smoke clouds employed for purposes of concealment.

Various poisonous gases were used intentionally during the war, the selection of a particular gas depending on its physiological properties and on the precise purposes for which it was required. Some of these gases could rightly be considered as lethal agents, and the prospect of obtaining a high mortality decided their employment under appropriate conditions in the field. In other cases, however, gases were used, the primary object of which was not to cause death but merely temporary disablement, for in many instances the military object could be gained quite as effectively by this means as by a lethal effect. As defensive measures against gas improved the temporary disabling power of a gas or its casualty-producing power, as distinct from its killing power, began to loom more and more largely in the picture.

Though poisonous gases and vapours may under appropriate conditions of administration have a widespread action throughout the body and affect a number of different organs simultaneously, they usually produce their most marked effect on some particular structure, especially when they are present in low concentration. Their action, therefore, may in some sense be regarded as specific, and it is possible on this basis roughly to classify the gases used for offensive purposes during the war into groups according to their most prominent action. Such a classification is by no means rigid, for each of the gases really partakes of the characters of two or more of the groups, but it has the merit of convenience. As a result of experience it has become usual to adopt the following classification of warfare gases :—

(i) *Acute Lung Irritants.*—The characteristic feature of these poisons is that they exert an intense irritant action on the deeper respiratory passages and in particular on the alveoli of the lungs. This results in the copious exudation of inflammatory fluid with acute pulmonary œdema. Death in the acute stage of poisoning is directly attributable to interference with the gaseous exchange between air and blood in the lungs owing to the accumulation of fluid in the pulmonary alveoli and the damage to the finer blood-vessels and structure of the lung. All these gases have an immediate irritant action on the eyes and on the upper respiratory passages, but the degree of this sensory irritation varies considerably with different members of the group.

(ii) *Lachrymators.*—In extremely minute concentration these have an immediate and violent irritant action on the eyes, which causes so profuse a flow of tears and so much pain and smarting that vision becomes impossible, though the effect hardly outlasts the exposure. Stronger concentrations may have the same action as the acute lung irritants.

(iii) *Direct Poisons of the Nervous System or Paralysants.*—Provided that the concentration is sufficient, these poisons act with extreme rapidity on the vital functions of the nervous system, death being in these circumstances a matter of a minute or two, if not of seconds. In low concentrations some of these gases may be quite ineffective, while others may still give rise to serious effects, such as inflammation of the lungs or eyes.

(iv) *Sensory Irritants of the Eyes, Nose and Upper Respiratory Passages* (sometimes termed *sternutators* owing to their liability to cause sneezing).—These have an effective action in concentrations which are always low, and in some cases a great deal less than are required in the case of the other warfare gases. They give rise to intense burning and aching pain in the eyes, nose, throat and chest, accompanied by nausea and extreme mental depression. These effects clear up rapidly, however, on withdrawal from the poisonous atmosphere.

(v) *Vesicants.*—The typical effects are inflammation and blistering of the skin, acute conjunctivitis, and intense inflammation of the mucous membrane of the respiratory passages, these effects as a rule only commencing to appear an hour or two after exposure to the poisonous atmosphere.

Death is but rarely caused by the direct effects of the poison, but when it occurs it is nearly always due to severe bronchopneumonia dependent on the secondary bacterial infection of the damaged and necrotic mucous membrane of the bronchial tubes.

Broadly speaking, the gases in groups (i) and (iii) may be regarded as lethal agents, and those in groups (ii) and (iv) as irritants capable of putting a man out of action immediately, though only temporarily, whilst the vesicants of group (v), though intensely poisonous, have, when used against troops that are well disciplined in defence against gas, a casualty-producing power enormously in excess of their killing power.

A list is given in Table I of the different poisonous gases that were actually used for offensive purposes during the war, arranged according to the above classification. Certain data are given, in addition, which are of importance if the toxicity of these gases in the field and the particular purpose for which they could be suitably employed in warfare are to be properly appreciated.

It will be seen that only two of the substances enumerated, or three if phosgene, which boils at +8° C., is included, are actually in the gaseous state at ordinary temperatures. Those that are liquids at ordinary temperatures require to be dispersed in the air in the form of a finely divided spray, when a proportion dependent on the fineness of the spray, on the boiling point and vapour pressure of the liquids, on the temperature of the air, and on the velocity of the wind will be converted into vapour. In some cases the effect of the actual particles of liquid in the air may have to be reckoned with, in addition to the vapour. It will be noticed that diphenyl-chlorarsine and diphenyl-cyanarsine are solids at ordinary temperatures, and in this case the physiological effects are to be attributed to the presence in the air of the actual solid substance in a finely particulate state rather than of its vapour.

Those substances which exist as gases at ordinary temperatures, such as chlorine and sulphuretted hydrogen, or are very easily vaporized, such as hydrocyanic acid and phosgene, are readily swept away by the wind, and it is possible, therefore, to traverse or occupy a gassed area with impunity a few minutes after a gas cloud of this character has passed over it, if due precautions are taken to avoid trenches, dugouts, or local hollows in the ground in which gas may still be lurking. Such gases fall within the category of non-persistent gases for military purposes.

TABLE I.

Substance.	Chemical Formula.	Date of Introduction.	Boiling Point, degrees Centigrade.	Vapour Pressure in mm. Mercury.			Approximate Concentration to incapacitate a Man in a few seconds owing to Sensory Irritation of the Eyes (Lachrymation) or Upper Respiratory Passages (Pain, Coughing).	Approximate Concentration which if breathed for more than one or two minutes would cause definite Bronchial or Pulmonary Lesions.	Used by : B = British ; F = French ; G = Germans ; A = Austrians.
				At 10° C.	At 20° C.	At 30° C.			
ACUTE LUNG IRRITANTS.									
Chlorine	Cl_2	1915	− 33·6	3,760	5,030	6,650	1 : 10,000	$>$1 : 10,000	B. F. G.
Phosgene	$COCl_2$	1915	+ 8	836	1,215	1,750	1 : 100,000	1 : 50,000	B. F. G.
Chlormethyl-chloroformate ("Palite," French)	$Cl.COO.CH_2.Cl$	1915	+ 105	3·6	5·6	—	1 : 100,000	1 : 10,000	F. G.
Trichlormethyl-chloroformate ("Diphosgene," British "Surpalite," French)	$Cl.COO.CCl_3$	1916	+ 128	5	10·3	16·3	1 : 200,000	1 : 50,000	F. G.
Chloropicrin	$CCl_3.NO_2$	1916	+ 112	10·8	18·9	30·5	1 : 200,000	1 : 50,000 (cumulative).	B. F. G.
Stannic chloride	$SnCl_4$	1916	+ 114	10·3	18·6	31·3	—	1 : 10,000	B.
Phenyl-carbylamine-chloride	$C_6H_5.N:CCl_2$	1917	+ 209	—	—	—	1 : 200,000	1 : 10,000	G.
Cyanogen bromide	$CNBr$	1918	+ 61·3 (M.P. 52°)	63·3 (15°)		119·5 (25°)	—	1 : 30,000	A.
Dichlor-methyl-ether	$(CH_2.Cl)_2:O$	1918	+ 105	—		—	1 : 10,000	1 : 10,000	G.
LACHRYMATORS.									
Benzyl bromide	$C_6H_5CH_2.Br$	1915	+ 198	about 1 mm. at 25°			1 : 2,000,000	—	G.
Xylyl bromide	$CH_3.C_6H_4.CH_2.Br$	1915	+ 216 to 220	—	—	—	1 : 2,000,000	—	G.

Ethyl-iodoacetate	$CH_2I.COOC_2H_5$	1916	+ 180	0·28	0·54	0·87	1 : 2,000,000 to 1 : 5,000,000	1 : 50,000	B.
Bromacetone	$CH_3.CO.CH_2Br$	1916	> +136 (decomp.)	1	—	—	1 : 2,000,000	> 1 : 10,000	F. A.
Monobrom-methyl-ethyl-ketone	$CH_2Br.CO.CH_2.CH_3$ .. or $CH_3.CO.CHBr.CH_3$ ..	1916 —	+ 145 + 133	— —	— —	— —	1 : 500,000	> 1 : 5,000	G. A.
Dibrom-methyl-ethyl-ketone ..	$CH_3.CO.CHBr.CH_2Br$ ..	1916	> + 53 (decomp.)	—	—	—			
Acrolein	$CH_2.CH.CHO$	1916	+ 52	140	—	—	—	—	F.
Methyl-chlorsulphonate	$SO_2 \langle {OCH_3 \atop Cl}$	1915	+ 132	—	—	—	—	—	G.
				PARALYSANTS.					
Hydrocyanic acid..	HCN	1916	+ 26·5	(455 at 15°)	603	860	> 1 : 2,000 (immediately fatal).	Practically no cumulative action.	B. F.
Sulphuretted hydrogen	H_2S	1916	− 61·8	16,500	—	—	1 : 1,000 (immediately fatal).	1 : 10,000 (affects eyes and lungs).	B.
				SENSORY IRRITANTS OF EYES, NOSE AND CHEST (STERNUTATORS).					
Diphenyl-chlorarsine	$(C_6H_5)_2AsCl$	1917	+ 333 (M.P. +43°)	0·02 mm. at 50°			< 1 : 10,000,000	1 : 50,000	G.
Diphenyl-cyanarsine	$(C_6H_5)_2AsCN$	1918	> + 300 (M.P. +31°)	—	—	—			
Ethyl-dichlor-arsine ..	$C_2H_5.AsCl_2$	1918	+ 156	—	—	—	1 : 500,000	1 : 20,000	G.
Ethyl-dibrom-arsine	$C_2H_5.AsBr_2$	1918	—	—	—	—	—	—	G.
N. ethyl carbazol	$(C_6H_4)_2N.C_2H_5$	1918	> + 190 (M.P. +68°)	—	—	—	—	—	G.
				VESICANTS.					
Dichlor-ethyl-sulphide (Thio-diglycol-chloride: "Mustard Gas," British; "Yperite," French).	$(CH_2Cl.CH_2)_2S$	1917	+ 217 (M.P. +13°)	0·01	0·06	0·09	—	1 : 1,000,000 with 60 min. exposure.	B. F. G. A.

The liquids of high boiling point, *e.g.*, phenyl-carbylamine-chloride, xylyl or benzyl bromides, ethyl-iodoacetate or dichlor-ethyl-sulphide, have a very high persistency on the ground, and even if they have been liberated by the explosion of gas shells enough actual liquid falls on the ground to contaminate the soil seriously in the neighbourhood of the burst. Such areas continue to yield a dangerous concentration of the vapour for hours or even for days as the liquid in the soil slowly evaporates, until the wind and the heat of the sun, or the slow hydrolysis of the substance by the moisture in the soil, finally dissipate the last residue of the poison. Substances with an intermediate boiling point have, of course, far less persistency, while such solids as diphenyl-chlorarsine may be regarded for practical purposes in gas warfare as non-persistent, though water derived from an area contaminated with these substances may have toxic properties.

It is difficult to realize at first what an enormous volume of gas has to be liberated in the open air to obtain even a small percentage in the atmosphere breathed. When gas is set free under these conditions even the gentlest breeze implies that it must become mixed with an immense volume of air, and upward currents and eddies in the atmosphere dependent on differences of air and ground temperatures and on the contour of the land soon spread the gas vertically, with the consequence that the concentration of gas in the air diminishes fairly rapidly as the distance to leeward from the point of emission is increased. Owing to this, the concentrations of gas that one is called upon to deal with in warfare are likely to be of the order of 1 or 2 parts in 10,000 in the case of substances which exist as gases at ordinary temperatures, or are very easily vaporized owing to their low boiling point, and of 1 or 2 parts in 1,000,000 in the case of the vapours of liquids of high boiling point, save in close proximity to the point where the gas is actually liberated. It is easy to see from the vapour pressure values given in Table I that even in ideal circumstances the concentration in the air of the vapour of the liquids of high boiling point can only be minute ; thus, in the case of dichlor-ethyl-sulphide, air at normal barometric pressure which is completely saturated at 10° C. with the vapour will only contain 1 part of the vapour in 76,000 by volume, and at 30° C. 9 parts in 76,000, and in the open air there would be no possibility whatever of attaining anything approaching full saturation.

It is evident, therefore, that warfare gases must be able to exert a toxic action in extremely low concentration if they are to be of any value. It is a matter of considerable difficulty to determine with any approach to accuracy the minimum concentrations necessary for military purposes. This naturally varies greatly according to whether a fatal effect or only temporary disablement is desired. Moreover, the figures are liable to be influenced by differences of individual susceptibility to the action of the poisons, and attempts to deduce the toxicity for man from experiments on the lower animals are rendered uncertain owing to the widely different susceptibilities of different species. The duration of exposure to the poisonous atmosphere is also a matter of great importance. Some gases, such as arseniuretted hydrogen, chloropicrin, and dichlor-ethyl-sulphide, are definitely cumulative in action, and in these cases the concentration of the gas and the duration of exposure are factors of more or less equal importance. In other cases the concentration of the gas is of far greater significance than the duration of exposure ; this is true in particular of hydrocyanic acid, which is practically non-cumulative in action, and holds good, at least to a considerable degree, in the case of such gases as chlorine and phosgene, the action of which can be readily neutralized by the body fluids.

Exposure to atmospheres containing a small proportion of poisonous substances can hardly be compared with the absorption of poisons in relatively massive doses from the alimentary canal or after hypodermic or intravenous injection, when they have the opportunity of acting on the most diverse organs. Though such gases as hydrocyanic acid and sulphuretted hydrogen can, if breathed in sufficient concentration, undoubtedly penetrate as such into the body, as is shown by their almost immediate action on the central nervous system, the action of the remaining gases that were used in the war appeared, in the concentrations which prevailed, to be limited entirely or almost entirely to the surfaces with which they first came in contact, even though these gases were stable in character and not easily neutralized. The respiratory organs, eyes and skin, in fact, bore the brunt of the attack. Yet even if one recognizes this, one must be prepared for serious effects which are really secondary to these primary lesions. Severe though temporary shortage of oxygen, resulting from acute pulmonary œdema or interference with the oxygen-carrying power of the blood, may exercise lasting effects on the heart, the central nervous system, or other organs in the body, while secondary bacterial infection may delay recovery or even be the prelude to a fatal termination, this factor being of particular importance in the case of poisoning by dichlor-ethyl-sulphide.

The figures for toxicity shown in Table I are sufficient to give some idea of the extreme potency of the various warfare gases. At the same time, one must be careful not to use these figures as a direct criterion of the real effect which is likely to be obtained in the field under actual conditions of warfare. It is one thing to expose to a poisonous atmosphere troops who have no means of protection, but it becomes quite a different matter when they have organized good defensive measures against gas. When once defensive organization has been perfected, much must depend on the actual disposition of the troops in the area exposed to gas, the precise surprise effect attainable, the condition at the time of respirators, protected dugouts, and arrangements for giving the alarm, the general anti-gas discipline and moral of the troops, and the facility with which the gassed area can be evacuated. The influence of these varying factors can hardly be gauged except by the test of actual warfare. Similarly, the more remote invaliding power, as opposed to the lethal or immediately disabling power, of the gas cannot be foretold with any certainty, but can only be ascertained by experience; yet this is a factor of the greatest military significance, for prolonged invalidism may constitute a very serious problem as soon as the ability to maintain the man-power of the fighting troops becomes a crucial factor. From the military point of view the purpose of gas warfare is, however, by no means limited to the actual production of casualties. It is of the greatest value as a harassing agent, and can be used to advantage for neutralizing hostile batteries, hampering the supply of food and munitions in the battle zone, interfering with the movements of troops, and seriously troubling men in billets in the front area. An area shelled with dichlor-ethyl-sulphide may be rendered untenable for days. The strain caused by continual attacks with gas, the personal discomfort and the reduction of fighting efficiency caused by wearing anti-gas respirators, and the knowledge that a cloud gas or projector attack may kill many men in what is an affair of but a moment or two without any risk to those who have released the gas, so that only ceaseless vigilance can prevent a heavy toll of casualties, are factors liable to undermine seriously the moral of even the best troops.

Methods of Liberating Warfare Gases.

Two methods were used during the war for liberating warfare gases, namely, the release of compressed gas from cylinders, and the employment of projectiles containing liquid or solid poisons. Each of these methods offers certain advantages and disadvantages which determine its value for military purposes, and it is necessary to deal with these in some detail if one is to understand the development of gas warfare and the bearing of this on the number and character of the casualties resulting from it.

Cylinder or " Cloud Gas " Attacks.—Cylinders containing the compressed gas were installed in the front line trenches opposite the sector to be attacked. These cylinders were fitted with delivery pipes which could be pushed forward over the top of the parapet so as to ensure that the gas was liberated well in front of the trench in which the troops operating the cylinders were standing. Under favourable wind conditions the valves of the cylinders were opened at a predetermined moment, and the gas issuing under high pressure from the ends of the delivery pipes was carried as a cloud upon the opposing positions. This type of gas attack is entirely dependent on the wind, and can only be conducted when both direction and velocity of the wind are suitable. The wind must be steady not gusty, and its speed must be sufficient to ensure that there is no risk of the gas eddying back on to the user's position, yet not so great as to cause undue dilution of the gas. Cloud gas attacks were made during the war with wind velocities varying from 3 to 20 miles per hour ($1\frac{1}{2}$ to 10 yards per second), but on the whole velocities of 4 to 8 miles per hour were considered most favourable.

In order to attain a sufficient concentration of gas in the cloud it is essential that the pressure under which the gas is contained in the cylinders shall be sufficient to ensure that they can be emptied of their contents with great rapidity on opening the valve, and that the poison shall be liberated in the gaseous form, leaving no pools of liquid to evaporate slowly in front of the trenches. Moreover, the gas should be in liquid form when under pressure in the cylinders if a sufficient quantity is to be provided without an undue weight or number of cylinders. A gas on expansion absorbs heat, thereby cooling the air with which it is mixed, and this effect is greatly enhanced if the gas has first to pass from the liquid into the gaseous state owing to the high latent heat of vaporization.

Lowering of temperature from these causes, and the selection of a gas, the density of which is greater than that of air, will help to keep the gas cloud low.

These requirements limit the choice of a suitable gas very considerably. Chlorine had much to recommend it. It is readily prepared in quantity and can easily be liquefied and stored in this condition in steel cylinders, while the boiling point is sufficiently low to ensure complete vaporization if an appropriate jet is used at the outlet. It is easy to understand, therefore, why the Germans selected this gas for their initial attempt. Its toxicity is quite sufficient if the opposing troops are unprotected by respirators, though, as will be seen from Table I, it is not to be compared in this respect with many of the other gases that were used at a later date. So soon, however, as protective measures were evolved and success in a cloud gas attack began to depend more and more on overwhelming the opposing troops with a strong concentration of gas before they had time to put on their respirators, something of greater potency than chlorine was needed. The choice fell on phosgene, for though its boiling point would have precluded its use by itself save possibly in hot weather, it could be effectively employed if mixed with a considerable proportion of liquid chlorine in the cylinders, or expelled through a suitable jet by the agency of some other compressed gas. A certain proportion of chloropicrin could also be employed, if mixed with chlorine, without much risk of contaminating the ground in front of the trenches with unvaporized liquid. In making such a mixture it was, of course, essential that the different substances should not react upon and neutralize one another.

The Germans employed in their cloud gas attacks either chlorine or a mixture of chlorine and phosgene (in some cases the phosgene was driven out of separate cylinders by means of another compressed gas), and sometimes they added chloropicrin. The British at first used chlorine, but most of their cloud gas attacks were made with a mixture of chlorine and phosgene. In addition they made trial in one or two attacks of sulphuretted hydrogen ; the latter gas is not, however, of a sufficiently high order of toxicity and has the further disadvantage that it is easily set on fire by the explosion of shells or bombs. The French used chlorine or a mixture of chlorine and phosgene. Hydrocyanic acid was not used in a cloud gas attack, for it is lighter than air and its toxicity was insufficient. The remaining gases were not found suitable for use in a cloud gas attack.

To all intents and purposes the only gases that were used in a cloud gas attack fell within the category of acute lung irritants, and the intention of the attack was undoubtedly to kill rather than to cause mere temporary disablement. To gain any material effect the attack had to be made on a sector of considerable length. The German cloud gas attacks were made on sectors varying in length from 1 to 5 miles, and this meant the employment of a number of cylinders running into thousands. The work of transporting these cylinders to the trenches and fixing them in position was of the heaviest description, and the presence of cylinders in the trenches always gave rise to a certain element of danger owing to the risk of cylinders being burst by shell fire, whilst the suspicion that a cloud gas attack was being prepared was the surest means of inviting a heavy artillery bombardment.

Gas Projectiles.—In certain respects this method offers considerable advantages over the cloud gas attack. The gas can be liberated at a point far distant from one's own positions, and in consequence of this one is far less dependent on the wind ; in fact, a distant target may be shelled with gas even if the wind is blowing directly towards one's own positions, for by the time the gas is carried back by the wind it has become so diluted as to be harmless. Gas shelling is most effective when there is little or no wind, for then the relatively small gas cloud which arises is not quickly dispersed. Battery positions, supply points, roads, villages and billets behind the line lie open to attack with gas at any time, and, whereas a cloud gas attack of any magnitude demands a properly organized trench line for its installation, gas shell can be used with great effect in open fighting.

Against these advantages, however, must be set certain disadvantages. Great care is needed in the construction of any form of gas projectile, lest the poison should leak out and cause serious casualties amongst those who have to handle the ammunition or serve the guns, whilst in some cases in which the poisonous substance has a chemical action on the metal of which the shell is composed the liquid has to be enclosed in a special container of lead, porcelain, or some other material. The amount of gas carried by an artillery shell is small in proportion to its weight, and good results can only be obtained by the expenditure of a great quantity of ammunition and by concentrated bombardments. Trench mortar bombs offer an advantage in this respect over artillery shell owing to the relative thinness of their walls. Clearly, therefore, the poison contained in a gas shell must be capable of exerting an effective toxic action in exceedingly low concentration; it must, in addition, be able to withstand the shock and the high temperature of the explosion without decomposition.

All the substances mentioned in Table I, with the exception of chlorine and sulphuretted hydrogen, were used either separately or as mixtures at different periods of the war for the filling of gas shell and trench mortar bombs. The lethal effect of artillery shell containing acute lung irritant substances cannot be regarded as of a high order under modern conditions of warfare when troops are well disciplined in defence against gas, since it is almost impossible to develop the required concentration of gas on the target with sufficient rapidity to overwhelm troops before they have had time to adjust their respirators or gain shelter in protected dugouts. Hurricane bombardments with trench mortar bombs are likely to be more effective in this respect. In any case, however, projectiles of this type have a most valuable harassing effect, since they compel respirators to be worn if casualties are to be avoided.

The British developed a most formidable method of using projectiles filled with acute lung irritant substances in the so-called "projector discharge" as described by Lefebure. The projector was a very simple form of large trench mortar with a range up to 1,500 yards, in appearance closely resembling an ordinary compressed gas cylinder with the top cut off, firing a projectile or bomb holding 30 lb. of liquid phosgene. These projectors were grouped in batteries and fixed, with due regard to elevation and direction, in specially constructed trenches some distance behind the front line. At the desired moment all the batteries were fired simultaneously by electrical means, and the bombs bursting on and around the selected target gave rise to a very dense gas cloud. This weapon was by no means accurate, and it was customary to fire in a single discharge anything from two or three hundred up to two or three thousand projectors. The general effect produced was similar to that of a cloud gas attack, save that a far higher local concentration of gas was obtained by this method, seeing that the gas cloud was actually developed *in situ* on the target, and did not have to be carried by the wind for a considerable distance before reaching its objective, whilst far better opportunity was afforded for surprising the enemy, since the noise of the projector discharge itself could be drowned by artillery and machine gun fire, and the first intimation of the attack might only be given by the falling and bursting of the bombs. This method was copied by the Germans, but they made only very limited use of it. Owing to the large volume of gas liberated in a projector discharge, considerable attention had to be paid to the direction and strength of the wind at the time, though the wind limitations were not so narrow as in the cloud gas attacks.

Many of the other poisonous substances mentioned above gave valuable results when used in gas shell, but by far the most effective substance used as a filling for artillery gas shell during the war was dichlor-ethyl-sulphide, owing to its peculiar properties and to the length of time that ground contaminated with this substance continued to yield a dangerous concentration of the vapour.

As the war progressed, a greater and greater tendency was noticeable, especially on the part of the Germans, to divide artillery gas shell for practical purposes into only two categories, depending on whether the poison persisted or did not persist on the ground after the explosion of the shell. Shells with a non-persistent filling, no matter whether that filling was primarily of a lung irritant, lachrymatory, or sensory irritant character, were used by the Germans quite indiscriminately in the later period of the war when there was any possibility that they would have to make an infantry attack over the area in question very soon after the cessation of the bombardment; the use of shells with persistent fillings, such as the lachrymators of high boiling point, and, in particular, dichlor-ethyl-sulphide, was restricted to areas which they had no desire to occupy, and which they wished to render untenable by their opponents except at the cost of innumerable casualties.

The Germans employed gas shell and trench mortar bombs of all calibres, and the Allies followed suit so far as their available supplies of gas would permit. The fillings used by the British for their gas shell and trench mortar bombs were phosgene, chloropicrin, chloropicrin and stannic chloride, ethyl-iodoacetate, hydrocyanic acid, and, in the end, dichlor-ethyl-sulphide. The toxicity of hydrocyanic acid was much over-estimated in the early part of the war, but it was one of the few poisonous substances that the British could easily produce in quantity owing to the pre-war development of the cyanide industry. As more effective substances became available its use was discontinued. The French employed phosgene, trichlor-methyl-chloroformate, chloropicrin, bromacetone, acrolein, hydrocyanic acid, and, in the last four months of the war, dichlor-ethyl-sulphide. A list of the different shell fillings used by the Germans and Austrians, together with the code names corresponding to the distinctive markings on the shell by which they were usually designated, is given in Table II.

The great majority of gas shells had only a small bursting charge, just sufficient to ensure the proper fragmentation of the shell and liberation of the gas contained in it without too great dispersion of the cloud, but Blue Cross shell containing the solid chlorarsine compounds had a heavy bursting charge in the middle of which was embedded a glass bottle containing the poison, and such shell combined the destructive properties of a high explosive shell with the harassing powers of a gas shell. At the end of the war the Germans showed a tendency to increase the bursting charges in their gas shell so as to obtain the advantage of increased moral and destructive effect. Gas shells were usually fused with either ordinary percussion fuses or with instantaneous contact fuses, the latter reducing the risk of gas being lost by absorption in the earth on the explosion of the shell On a few occasions air bursts of German Yellow Cross or Blue Cross shell due to the employment of a time fuse were reported

Poisonous Gases not used deliberately for Offensive Purposes.

Of these gases, one, the so-called nitrous fumes, belongs to the group of acute lung irritants, and two, carbon monoxide and arseniuretted hydrogen, may be regarded as falling within a category which has not yet been mentioned, namely, gases that interfere with the respiratory properties of the blood. Carbon monoxide has a high affinity for the hæmoglobin in the red blood-corpuscles and tends to combine with it to the exclusion of oxygen, while arseniuretted hydrogen causes destruction of the red blood-corpuscles accompanied by hæmoglobinuria, jaundice, and nephritis. Lastly, reference must be made to atmospheres which are dangerous owing to simple reduction of the oxygen percentage, without the addition of any poisonous gas.

Nitrous Fumes (nitric oxide, NO, and nitrogen peroxide, NO_2 or N_2O_4).—If cordite, dynamite, blasting gelatine, and certain other nitro-explosives are set on fire and continue to burn without explosion, considerable quantities of orange-yellow nitrous fumes may be evolved. Danger is therefore likely to arise if ammunition is on fire, especially if this occurs in a fairly confined space. Nitrous fumes are formed in

TABLE II.

Fillings of German Artillery and Trench Mortar Gas Shell.

Code Name or Distinctive Marking on the Shell.		Chemical Substance.	Used for.
German.	English equivalent		
T-Stoff ..	T-substance ..	Xylyl bromide and/or benzyl bromide.	Artillery.
T-grün ..	Green T-substance.	Xylyl bromide + brom-methyl-ethyl-ketones.	Artillery.
K-Stoff ..	K-substance ..	Chlormethyl - chloro - formate.	Artillery and trench mortars.
C-Stoff (K2-Stoff).	C-substance (K2-substance).	Trichlormethyl - chloro - formate.	Artillery and trench mortars.
B-Stoff ..	B-substance ..	Brom - methyl - ethyl ketones.	Trench mortars.
D-Stoff ..	D-substance ..	Phosgene.	Trench mortars.
Grünkreuz	Green Cross ..	Trichlormethyl - chloro - formate; or brom-methyl-ethyl-ketones; or phenyl-carbylamine chloride.	Artillery.
	H.E. Green Cross (Shell marked with a double or Lorraine cross (‡) in green).	Phosgene + large H.E. charge.	Artillery.
Grünkreuz 1	Green Cross 1..	Trichlormethyl - chloro - formate + chloropicrin	Artillery.
Grünkreuz 2	Green Cross 2..	Phosgene + trichlor - methyl-chloroformate + diphenyl - chlor - arsine.	Artillery.
Grünkreuz 3 (*vide infra,* Gelbkreuz 1)	Green Cross 3 (*vide infra,* Yellow Cross 1)		
Blaukreuz	Blue Cross ..	Diphenyl-chlorarsine; or ditto + diphenyl - cyanarsine or N. ethyl carbazol. Large H.E. charge in all cases.	Artillery.
Gelbkreuz	Yellow Cross ..	Dichlor - ethyl - sulphide + 15–20 per cent. of solvents, *e.g.*, carbon tetrachloride, chloro-benzene, nitrobenzene.	Artillery and trench mortars.
	H.E. Yellow Cross. (Shell marked with a double or Lorraine cross (‡) in yellow).	Dichlor - ethyl - sulphide and solvents + large H.E. charge.	Artillery.
Gelbkreuz 1 (re-named Grünkreuz 3, July 1918)	Yellow Cross 1 (re-named Green Cross 3, July 1918)	Ethyl-dichlor-arsine + dichlor-methyl ether; or ditto + ethyl-dibrom-arsine.	Artillery.

TABLE II—*cont.*

Fillings of Austrian Artillery Gas Shell.

Code Name, or Distinctive Marking on the Shell.		Chemical Substance.
German.	English equivalent	
C-Stoff ..	C-substance ..	Cyanogen bromide.
B-Stoff ..	B-substance ..	Bromacetone.
	CB-shell ..	Cyanogen bromide + bromacetone; or brom-methyl-ethyl-ketones; or cyanogen bromide + brom-methyl-ethyl-ketones.

Fillings of German Gas Projector Bombs.

Phosgene.
Phosgene + trichlor-methyl-chloroformate + chloropicrin.
Phosgene + chloropicrin.
A mixture of about equal parts of diphenyl-chlorarsine and H.E.

Fillings of German Gas Hand Grenades.

Type of Grenade.	Distinguishing Mark.	Chemical Substance.
Spherical grenade ..	Red "B" ..	Brom-methyl-ethyl-ketones.
Spherical grenade ..	Red "C" ..	Methyl-chlorsulphonate + 5 per cent. of methyl sulphate.
Stick grenade ..	Blue "C" ..	Diphenyl-chlorarsine + an equal weight of H.E.

Note.—Spherical glass hand grenades filled with chlorsulphonic acid were also employed for smoke-producing purposes.

mining operations when a blasting charge does not detonate but in part merely burns. The fumes are readily absorbed by moisture, and in consequence of this cases of poisoning may be uncommon if a tunnel is being driven through damp ground, though cases have been frequent in such mining areas as the Rand, where the galleries are driven through dry rock, as noted by Irvine and Macaulay. The history of mining affords instances in which as many as twenty lives have been lost at a time owing to a box of dynamite catching fire underground.

Nitrous fumes were the cause of no serious cases of poisoning during the operations on land, but they constituted a very grave danger at sea when the propellant charges of guns were set on fire during action, especially when this happened between decks or in other relatively confined spaces. This form of poisoning is noted by Fairlie.

Carbon Monoxide (CO).—This gas proved to be of serious importance during the war. It is formed in large volumes on the explosion or detonation of explosives and when the combustion of carbonaceous material takes place in a limited supply of air.

During mining operations the galleries were not infrequently flooded with the gas after the explosion of either a British or a hostile mine or camouflet, or as the result of the explosion or burning of a blasting charge. In these circumstances the gas is liable to be driven into the ground disturbed by the explosion and to come welling out later, especially if the barometer commences to fall after the explosion, whilst it was sometimes met with in the form of pockets of gas when new galleries were driven through ground disturbed by a previous explosion. Carbon monoxide was even known to be driven out of the shafts into adjacent trenches after the explosion of a mine. On one occasion a sample of air taken from one of the mining galleries as late as four days after a camouflet had been exploded by the Germans was found to have the following composition :—

Oxygen	16·77	per cent. by volume.
Carbon dioxide	4·36	,, ,,
Carbon monoxide	1·65	,, ,,
Hydrogen	1·13	,, ,,
Other combustible gases reckoned as methane	0·29	,, ,,
Nitrogen	75·80	,, ,,

Though naturally it was the men of the tunnelling companies who in the main had to face this danger, instances were not wanting of infantry who had entered a mine shaft to gain shelter from shell fire being overcome by carbon monoxide, of the presence of which they were unaware owing to the fact that the gas is odourless and non-irritant.*

A large volume of carbon monoxide is generated in the explosion of H.E. shell. In the open air, however, the danger of poisoning proved negligible, for the gas is but slowly absorbed and a considerable length of exposure is necessary before material symptoms arise if only a low concentration of the gas is present in the air. When a high explosive shell, particularly if it has a delay action fuse, penetrates the soil and bursts in the neighbourhood of a deep dugout or other relatively confined space, the carbon monoxide generated in the explosion may find its way into the dugout and poison the occupants, and this actually occurred on a number of occasions. There is little doubt that many of the men who were buried by the explosion of shells perished from the effects of carbon monoxide rather than from violence.

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* See Chapter XX for detailed information regarding the occurrence of carbon monoxide poisoning during mining operations.

In view of these facts one might be tempted to class carbon monoxide as a " warfare " gas. This is, however, hardly a fair view, for in probably every case the primary object for which the explosive was employed was its destructive effect, whether it was used in the form of mine, camouflet, or shell, and it was to chance rather than to design that one must attribute the deadly effects of the fumes. At the same time, both sides learnt by experience to regard explosives not only as destructive agents, but in suitable circumstances as the source of a most dangerous gas. Carbon monoxide as such was never used for offensive purposes.

A good many cases of carbon monoxide poisoning of a moderate degree of severity occurred in gun-pits, and especially in closed machine gun emplacements, as noted by J. F. Mayne, owing to the blow-back from the gun, and at one period the disablement of machine gun crews from this cause became a somewhat serious question till measures were taken to hinder the access of the fumes from the guns into the emplacement. There was a similar risk in the case of tanks, and leakage of exhaust gases from the engine into the interior of the tank offered an additional source of carbon monoxide.

There is always the risk of carbon monoxide poisoning in the interior of burning buildings, and a similar but even greater danger is encountered when the timbering in a mine or deep dugout catches fire.

A number of cases of carbon monoxide poisoning occurred during the war owing to open coke braziers being used in dugouts or in small, ill-ventilated billets behind the line. In the winter the immediate prospect of comfortable warmth was apt to lead men to disregard warnings respecting the danger of braziers, and to lie down to sleep heedless of the fact that they had omitted to remove the brazier and had blocked practically all ventilation. Occasional instances were reported where fumes from the exhaust gained entry into motor lorries and caused symptoms of carbon monoxide poisoning in men inside them.

Arseniuretted Hydrogen (AsH_3).—This gas did not figure during the warfare on land. S. F. Dudley states that it occasionally gave rise to trouble in submarines, when small amounts of the gas were formed during the charging of the accumulators, the lead plates of which at times contained traces of arsenic.

Simple Reduction of the Oxygen Percentage in the Atmosphere.—Oxidation of organic or mineral matter in the soil sometimes leads to serious reduction of the oxygen percentage in the air of mines, wells, and the like. Occasionally, in fact, the atmosphere in such places consists almost entirely of nitrogen with or without the admixture of a certain proportion of carbon dioxide, and a rash entry into such an atmosphere may result in immediate asphyxia with practically no warning symptoms. A similar grave reduction of the oxygen percentage in the air may occur in any closed space containing decomposing organic matter, such as has been noted by R. C. Frederick, and on at least one occasion during the war when decomposing grain was being cleared from a ship's hold loss of life was to be attributed to this cause. During mining operations it was not infrequent to find the air in the galleries somewhat deficient in oxygen owing to the difficulty of providing adequate ventilation, though this deficiency was insufficient to give rise to any material effect.

Smoke Clouds.

Artificial smoke clouds were employed extensively during the war to conceal movements of assaulting troops, to hinder the co-operation of artillery with infantry, and to mask positions from direct hostile observation from the ground or from the air as occasion demanded. In practice such smokes could be considered non-toxic, though a thick cloud might have trifling irritant properties. The Germans made use of chlorsulphonic acid, $SO_2 < \genfrac{}{}{0pt}{}{CL,}{OH}$ and sulphur trioxide, SO_3, in artillery and trench mortar bombs to some extent, and the former compound was also used by them in hand grenades as well as in the large smoke canisters (Nebeltopf) from which smoke clouds were liberated for the purpose of concealing their own battery positions, buildings, and the like. The German H.E. shell often contained a smoke producer consisting of red phosphorus, paraffin wax, and arsenic to assist ranging. The British, who made far more use than the Germans of smoke clouds for masking the flanks of an attack and for similar purposes, employed trench mortar bombs and artillery shell filled with phosphorus which gave off a very intense cloud of white smoke on explosion, and in addition they made extensive use of smoke cases or hand grenades in the earlier period of the war when the use of smoke clouds was being developed. The hand grenades were filled with a slow-burning mixture of which the basis was mainly pitch, saltpetre, and sulphur. After ignition they were thrown over the parapet from the front trenches in large numbers if the wind was favourable. Smoke clouds of different kinds also figured in the naval warfare.

Incendiary shells do not come into the subject of gas poisoning. Apart from any actual incendiary value their effect was perhaps more moral than anything else in the actual battlefield. The Germans made limited use of shell or trench mortar bombs filled with thermite, sodium, inflammable celluloid, or yellow phosphorus. The British mainly relied on Stokes' mortar bombs containing thermite (a mixture of powdered aluminium and ferric oxide), and occasionally used bombs filled with oil in projector discharges.

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CHAPTER IX.

DEVELOPMENT OF GAS WARFARE.

IN giving an account of the development of gas warfare by the Germans and an estimate of the losses that the British suffered as a consequence the subject may be subdivided with advantage into the periods shown in Table I.

TABLE I.

Period.	Method of employing Gas.	Gas used.	Individual Protection for Troops.
1. April and May 1915 (6 attacks)	Cylinders (*i.e.*, cloud gas)	Chlorine ..	*Nil* at first; cotton waste respirators in last attack.
2. April 1915 to July 1916.	Gas shell ..	Lachrymators, *e.g.*, xylyl bromide.	*Nil* at first, then in succession — cotton waste respirators, goggles, fabric helmets (Hypo. P, PH, and PHG), a few large box respirators for special units.
3. December 1915 to August 1916 (6 attacks).	Cylinders	Chlorine and phosgene.	Fabric helmets (P in December, subsequently PH or PHG); a few large box respirators for special units.
4. July 1916 to July 1917 ("Lethal" shell period).	Gas shell	Phosgene, diphosgene, chloropicrin, also lachrymators.	PH or PHG helmets at first. Small box respirators introduced end of August 1916, issue complete early in 1917.
5. July 1917 to end of the war (Mustard gas period)	Gas shell	*Yellow Cross* (Mustard gas); *Green Cross* (Phosgene, diphosgene, chloropicrin, + in some cases chlorarsines); *Blue Cross* (Chlorarsines + large H.E. charge).	Small box respirators (from April 1917 onwards these contained a filter to remove solid substances existing in the particulate state in gas clouds).
6. December 1917 to May 1918 (16 bombardments).	Projectors	Phosgene, diphosgene, chloropicrin, chlorarsines.	Small box respirators.

These periods do not correspond with consecutive intervals of time, but are determined by the relative prominence of the particular chemical substances or offensive methods employed, and it will be noticed that the different periods overlap one another to a great extent.

In order to gain a true insight, however, into the effectiveness of poisonous gases as weapons in the field, attention must not be confined solely to gas warfare as experienced at the hands of the Germans, but the British methods for the offensive use of gas and the results obtained by them must also be taken into account.

The German Cloud Gas Attacks of April and May 1915.

The commencement of the second battle of Ypres was marked by the initiation of gas warfare, for on the evening of 22nd April, 1915, at 5.30 p.m., the Germans released gas from cylinders in the neighbourhood of Langemarck opposite the sector held by the French troops.

There was no warning of the attack ; it came as a complete surprise. All of a sudden jets of white smoke were seen to rise from numerous points in the German front line, and these quickly united to form a thick white cloud in front of which could be distinguished a haze of greenish-yellow vapour. The cloud drifted along the ground with the breeze and in a few moments enveloped the men in the trenches. The poisonous effect of the fumes was immediate. Choking, coughing, retching, gasping for breath, and half blinded, it is no wonder that the troops were seized with terror at the enemy's expedient and gave ground, stumbling back through heavy shell fire in their efforts to find some escape from the deadly fumes. The German infantry followed up the gas attack, finally occupying ground up to the Yser canal between Steenstraate and Het Saas.

The Canadian Division held the sector immediately to the right of the French position and their left flank was affected by the gas, whilst they had to swing back to conform with the retirement of the French ; but worse was in store for them, for on 24th April the Germans released another gas cloud in the Langemarck sector the full brunt of which fell upon them. The trenches held by the Canadians were in many places only 200 yards or less from the enemy, but they faced the attack, unprotected as they were, and numbers died where they stood rather than yield ground. As the Germans pressed forward at the close of the gas attack the Canadians made a counter-attack from the support lines in spite of the fact that the troops were severely affected by the gas cloud, and though the enemy gained some ground he did so at great cost.

The nature of the gas was quickly identified from its chemical action on brass buttons and other accoutrements, from the symptoms of those who survived the effects of the gas, from the pathological changes found at autopsy, and from the accounts of those who had witnessed the liberation of the gas cloud. Dr. J. S. Haldane, at the request of the Secretary of State for War, proceeded to France on 26th April to investigate the effects of the gas and to offer suggestions as to how the danger could be met. He was accompanied by Professor H. B. Baker, with a view to making enquiries into the chemical side of the question. The following sentences are taken from the report which Dr. Haldane submitted to the Secretary of State for War after examining casualties suffering from the effects of gas in the casualty clearing stations at Bailleul :—

> "These men were lying struggling for breath and blue in the face. On examining the blood with the spectroscope and by other means, I ascertained that the blueness was not due to the presence of any abnormal pigment. There was nothing to account for the blueness (cyanosis) and struggle for air but the one fact that they were suffering from acute bronchitis, such as is caused by inhalation of an irritant gas. . . . One of them died shortly after arrival. A *post-mortem* examination was conducted in our presence by Lieutenant McNee. The examination showed that death was due to acute bronchitis and its secondary effects. There was no doubt that the bronchitis and accompanying slow asphyxiation were due to the irritant gas. Lieutenant McNee also examined yesterday the body of a Canadian sergeant who had died in the casualty clearing station from the effects of gas. In this case also very acute bronchitis and œdema of the lungs caused death by asphyxiation. . . . The symptoms and the other facts so far ascertained point to the use by the German troops of chlorine or bromine for purposes of asphyxiation. There are also facts pointing to the use in German shells of other irritant substances, though in some cases at least these agents are not of the same brutally barbarous character as the gas used in the attack on the Canadians. The effects are not those of any of the ordinary products of the combustion of explosives."

This report was published in the English newspapers on 29th April, 1915. The gas shell to which Dr. Haldane alluded were lachrymator shell containing "T-Stoff," or xylyl bromide ; they were used sparingly at first, and a number of days elapsed before a blind shell was obtained and the poison definitely identified. The greenish-yellow colour of the gas cloud coincided well with the suggestion that chlorine was the main, and probably in fact the only, constituent. The thick white cloud which appeared at the point where the gas was liberated was evidently due to the condensation of moisture in the air owing to the lowering of the temperature caused by the expansion of the chlorine as it escaped from the cylinders.

On 1st, 6th, and 10th May, 1915, a fresh series of cloud gas attacks were made south of the Menin Road against the Hill 60 sector where the fighting was severe, and then on 24th May, 1915, a cloud gas attack of considerable magnitude was made from the Menin Road to Sanctuary Wood, followed later in the day by a serious infantry attack ; lachrymator shell were employed on a really extensive scale for the first time during the last of these attacks.

It is practically impossible to form any accurate idea of the number of casualties and deaths directly attributable to gas in this series of cloud attacks. A large number of men were killed outright by gas in the field, but deaths due to this cause are included in the casualty lists under the general heading " killed in action," for the severity of the fighting and the fact that the Germans gained ground allowed little opportunity for distinguishing those who died from the direct effects of gas from those killed by shell fire or rifle bullets. Again and again officers and men who went up in support as the infantry fighting developed described how they passed men lying in groups in the trenches and on the roads who had apparently died of asphyxia. There is also much uncertainty as to the number of casualties due to gas poisoning who fell into the hands of the enemy. So far as can be ascertained from the war diaries of medical units, approximately 7,000 gas casualties were admitted to the field ambulances and casualty clearing stations, though these probably did not include casualties in Canadian units, which must have reached a large number. The casualty lists for May and June 1915 record about 350 deaths from gas poisoning. These deaths must be attributable to the April and May cloud attacks, and appear to represent only those cases that died in medical units, deaths on the field never having been recorded as specifically due to gas.

That the number of gas casualties was very great and the true death-rate high in these early gas attacks is not surprising. At first the troops had no means of protection at all against the gas. Immediately after the first gas attack instructions were issued to the troops regarding the improvisation of simple respirators, by means of handkerchiefs soaked in sodium bicarbonate solution and the like, and some at least of the troops had such respirators during the attacks on Hill 60, but these hasty improvisations were for the most part quite inadequate. By 24th May the issue to the troops of the first official respirator (a cotton waste pad to cover the nose and mouth and moistened with a solution of hyposulphite of soda, sodium bicarbonate, and glycerin) had been completed, but in the gas attack on that date lack of instruction led only too frequently to the gross misuse of this respirator, while many of the troops unfortunately still placed their reliance upon improvised respirators, either made locally or obtained from England, which were hopelessly inefficient owing to errors in construction or insufficiency of absorbing power. All the gas attacks of April and May 1915 were made therefore against unprotected or practically unprotected troops.

The Germans made no further cloud gas attacks on the British front for seven months, and this respite gave time for the manufacture and issue of a better type of respirator as well as for the proper training of the troops in the use of the respirator and in more general defensive measures against gas. These included continuous observation of the direction of the wind, so that warning might be given to the troops as soon as it reached a dangerous quarter which might allow the enemy to make a cloud gas attack, arrangements for spreading the alarm of a gas attack, methods for clearing gas from trenches and dugouts, and methods of protecting the entrances of dugouts so as to prevent the admission of gas.

Lachrymator Gas Shell, April 1915 *to July* 1916.

" T " shell, containing xylyl bromide, were first used in the early cloud gas attacks, and their employment for neutralizing batteries and hindering the bringing up of supports soon became frequent. In the earlier days bombardments with these shell were on more than one occasion mistaken for a cloud gas attack owing to the inexperience of the troops.

Though these lachrymator shell had no mean harassing value they caused but few casualties, for the lachrymation, even if severe and distressing at the time, quickly passed off when the men were withdrawn from the irritant atmosphere. Occasionally men were subjected to a stronger dose of the lachrymatory gas, for bombardments with " T " shell were sometimes directed on trenches, dugouts, or shelters occupied by infantry, and the heaviness of the shelling, particularly if the " T " shell were accompanied by H.E. shell or shrapnel, might prevent them from leaving shelter and withdrawing at once from the contaminated area. In such cases nausea, coughing, and vomiting might put the affected troops temporarily out of action, for the early respirators and protective helmets were not very effective against xylyl bromide vapour; but even in these cases recovery was very rapid when once the men got away from the poisonous atmosphere, and rest for a day or two in a medical unit in the army area was as a rule all that was required to render them fit for duty again. In the autumn of 1915 a general issue of goggles was made in the hope of protecting the eyes against the lachrymatory effect, for it was this more than anything else which hampered the troops.

The largest group of casualties caused by lachrymator shell occurred during the battle of Loos, when some 550 cases were admitted to medical units. No deaths were attributable to the action of simple lachrymator substances, save perhaps in one or two chance instances when a lachrymator shell burst very close to a man or exploded after penetrating a dugout or shelter. In ordinary circumstances a lethal concentration of the gas could not be attained owing to the high boiling point of the liquid, and the stopping power of the respirator or helmet was sufficient to protect the lungs from material injury even though enough of the vapour penetrated to cause great temporary discomfort and profuse lachrymation. The Germans continued to use lachrymator shell throughout the war as harassing agents, though in much diminished numbers in the last eighteen months, when far more effective types of gas shell came into use.

Cloud Gas Attacks, December 1915 *to August* 1916.

The next German cloud gas attack upon the British, after the original series, was made on 19th December, 1915, and this was followed by further cloud gas attacks during 1916 on 27th, 29th and 30th April, 17th June, and 8th August, after which date no more cloud gas attacks were made on the British front, though the Germans still continued to use this method at intervals on other parts of the Western Front until June 1917. It will be convenient to take these attacks together as one group, for they had many features in common. The earlier cloud attacks of April and May 1915 had been made, as noted above, against unprotected troops, but in the subsequent attacks the troops were all equipped with efficient respirators and much attention had been devoted to general defensive organization and training against gas. The original emergency cotton waste respirator had been replaced by a protective helmet made of flannelette soaked in an absorbent solution, which completely covered the head. Several forms of these helmets, differing in their capacity for absorbing the poisonous gases that appeared likely to be used, were issued in succession to the troops. The "P" helmet, soaked in sodium phenate solution, which had the power of absorbing both chlorine and phosgene, was in use at the time of the cloud attack of 19th December, 1915, and the "P H" helmet, which had an increased power of absorbing phosgene owing to the presence of hexamine (*i.e.*, hexamethylene tetramine or urotropine), as well as sodium phenate, was in use at the subsequent attacks. By the time of the cloud attacks of April 1916 the "large box respirator," which afforded greatly increased protection, had been issued to special troops, such as machine gun personnel, signallers, and selected artillery personnel.

All these gas attacks were made at night or in the early morning, at a time when atmospheric conditions were most suitable and darkness rendered it difficult to distinguish the commencement of the liberation of gas. In the original gas attacks chlorine alone was probably used, but in the second series phosgene was certainly used in addition, the proportion of phosgene to chlorine being greatly increased in the later attacks. This implied an increase in the toxicity of the cloud, and in addition to this the Germans endeavoured to attain a really high concentration of the gas in the air by liberating it from the cylinders as quickly as possible, though this meant curtailing the duration of the gas attack. Owing to the slow dispersal of the gas cloud by the wind from low-lying areas or trenches it was by no means easy to determine with accuracy the actual duration of the emission of gas, but in some of the later cloud attacks the period of discharge of gas was undoubtedly cut down to as little as ten minutes. The aim of the Germans was clearly to surprise the troops with a deadly concentration of gas before they had time to adjust their protective helmets. Once protection was gained there was little chance of the gas doing any harm, but a single breath of air containing so high a concentration of gas as was now reached would cause coughing and gasping of such severity as to render it difficult, if not impossible, to adjust the helmet, and men who were slow in getting on their helmets were therefore likely to fall a prey to the fumes.

Some idea of the heavy concentration of gas attained in these attacks is given by the fact that discomfort was caused in the open air, and helmets were even worn by some troops, on 19th December, 1915, at Vlamertinghe, about 8,000 yards behind the front line; on 30th April, 1916, at Bailleul, 11,000 yards behind the front line; and on 8th August, 1916, at Busseboom and even at Poperinghe, 13,000 and 15,000 yards respectively behind the front line.

The sectors involved in these attacks, and the time when the attacks commenced are shown in Table II.

TABLE II.

German Cloud Gas Attacks, December 1915 to August 1916.

Date.	Sector.	Front involved in yards.	Wind: Miles per Hour.	Attack commenced.
19.12.15	Wieltje ..	4,400	—	5.15 a.m.
27.4.16	Hulluch ..	3,500	E. 3–4	5.0 a.m., first cloud mainly smoke; 6.30 a.m., gas cloud.
29.4.16	Hulluch ..	Flanks of same sector as on 27.4.16.	N.E. 5–6	4.0 a.m.
30.4.16	Wulverghem	3,500	E.N.E. 9–12	1.0 a.m.
17.6.16	Wulverghem	3,100	—	12.35 a.m.
8.8.16	Wieltje ..	1,700	E. 3–5	10.0 p.m. on 1,000 yd. front. 10.30 p.m. on 700 yd. front.

So similar in character were these six cloud gas attacks that it will be sufficient to give the details of but a single one as a typical instance. The cloud attack of 30th April 1916 has been selected for this purpose, as it affords the most complete data.

German Cloud Gas Attack on 30th April, 1916.

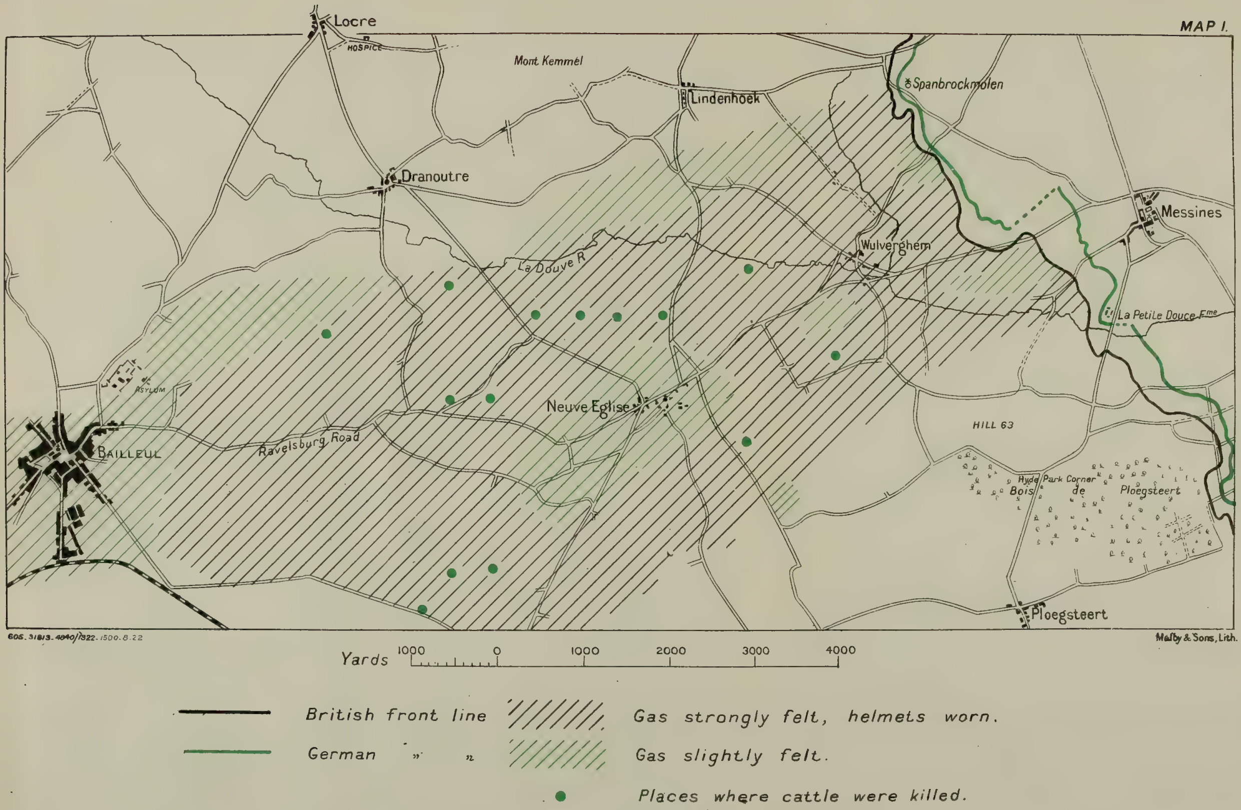
The brunt of this attack fell on the 24th Division, though the right brigade of the 3rd Division was also involved. The units mainly affected were the following, in order from north to south :—

3rd Division, 76th Brigade ..	10th Royal Welsh Fusiliers.
24th Division, 72nd Brigade ..	1st North Staffs.
..	8th Queen's.
73rd Brigade ..	2nd Leinsters.
	13th Middlesex.

The gas attack was not unexpected. More than once British artillery fire had broken up gas cylinders in the German trenches, and two deserters on 25th April stated that gas had been installed and was to be used as soon as the wind was favourable. Since 22nd April the wind had remained continuously in a dangerous quarter, and ever since that date the " gas alert " had been in force. At 9.25 p.m. on 29th April two more deserters entered the trenches held by the 3rd Division and stated that the enemy intended to make a gas attack the same night or early on the following morning, and warning was immediately circulated to all troops in the threatened sector.

The gas was released at 12.35 a.m. on 30th April under cover of heavy rifle and machine gun fire all along the front of 3,500 yds. from Spanbroekmolen to La Petite Douce Ferme with the exception of two small sectors (*see* Maps 1 and 2). The alarm was effectively propagated back from the trenches by gongs and sirens. In the northern part of the sector the emission of gas was continuous and only lasted some ten minutes, but farther south the gas was released in two distinct waves, the total duration of the gas attack at this point being from thirty to forty minutes. Heavy artillery barrages were simultaneously laid down by the Germans on points a short distance behind

GERMAN CLOUD GAS ATTACK, APRIL 30TH 1916.



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the trenches, and immediately after the gas cloud had drifted away they attacked, mainly at those points opposite which no gas had been liberated, apparently for the purpose of destroying mine shafts. Shell or trench mortar bombs containing chlormethyl-chloroformate were used against the front line and a few lachrymator " T " shell were fired upon the support lines, but they do not seem to have done any damage worth mentioning.

The gas cloud was carried by an E.N.E. wind with a velocity of 9 to 12 miles per hour over Wulverghem, Neuve Eglise, and Bailleul, passing south of Lindenhoek and Dranoutre, and its course is shown in Map 1.* The concentration of the gas fell off rapidly on the flanks of the cloud, but even in Bailleul, some 11,000 yds. from the line, it was still sufficiently strong to cause coughing and even vomiting in a few cases, amongst those who were in the open air, though closure of windows and doors prevented the gas from attaining a material concentration within the houses. On the high ground just about Neuve Eglise the concentration was fairly low, but it was again severe on the Ravelsberg Ridge farther to the west.

Grass and other vegetation were turned yellow by the gas as far back as 1,200 yds. from the front line. Rats were killed in the trenches in large numbers. Eleven cows, twenty-three calves, one horse, one pig, and fifteen hens were killed in the fields behind the lines by gas, and a number of other cattle and pigs showed signs of being affected by the gas. Places at which cattle were killed are shown in Map 1. Taking all the facts together, a really dangerous concentration for an unprotected man must have extended up to about 1,500 yds. from Bailleul, or 9,000 to 10,000 yds. from the point where the gas was installed. It was estimated that approximately 14,000 of the troops had to put on gas helmets during the attack, but this figure is bound to include a good many men on the outskirts of the cloud who assumed their helmets as a precautionary measure on receiving the alarm rather than from actual necessity.

In spite of the fact that the troops were standing to arms in expectation of the attack, the men in the front line received hardly any warning that the gas had actually been released before it was upon them. In some places the cloud was seen to arise from the opposing trenches as a white mist. The hissing of the gas as it escaped from the cylinders was audible at some points of the line, but it was effectively drowned by the rifle and machine gun fire at other points. In the north of the sector attacked the opposing trenches were in places only 40 yards apart, and it was merely a matter of seconds before the gas cloud reached the British line in high concentration, for with the prevailing wind the cloud would traverse 50 yds. in ten seconds.

At this time the standard anti-gas equipment of the troops was the " P H " helmet, though the original " large box respirator " had been issued to special troops such as machine gunners, signallers, and selected artillery personnel, as already stated. The latter device proved extremely successful in this attack for the facepiece of the respirator could be adjusted more rapidly than could the " P H " helmet, and hardly a casualty occurred among the men so equipped. In the 72nd Brigade the helmets were carried in their protective satchels. In the 76th Brigade the helmets were, however, removed from their satchels previous to the attack and worn like caps on the head with the skirt rolled up, a method which had recently been advocated as it had been found that full protection could be obtained more rapidly by this method than if the helmet had to be taken from its satchel and unfolded when the alarm was given.

The number of gas casualties that occurred amongst the troops was considerable in spite of the warnings that had been circulated and their consequent readiness for the attack. There were, of course, a few more or less isolated details who had received inadequate warning or had failed to appreciate the significance of their instructions, and some men were caught by the gas whilst asleep, but casualties resulting from this cause formed but a fraction of the whole. The speed with which the cloud reached the trenches, and the concentration of the gas, were such that a man was bound to fall a victim if he hesitated in the slightest in putting on his respirator or fumbled in adjusting it. As one would expect, therefore, the great bulk of the casualties occurred among the troops actually holding the line at the time, and in any one of these battalions the majority of the casualties occurred in the trenches nearest to the enemy. This is shown in Table III, in which the distance from the enemy at which casualties occurred is given for the 72nd and 73rd Brigades. The position of the companies is also shown in Map 2.

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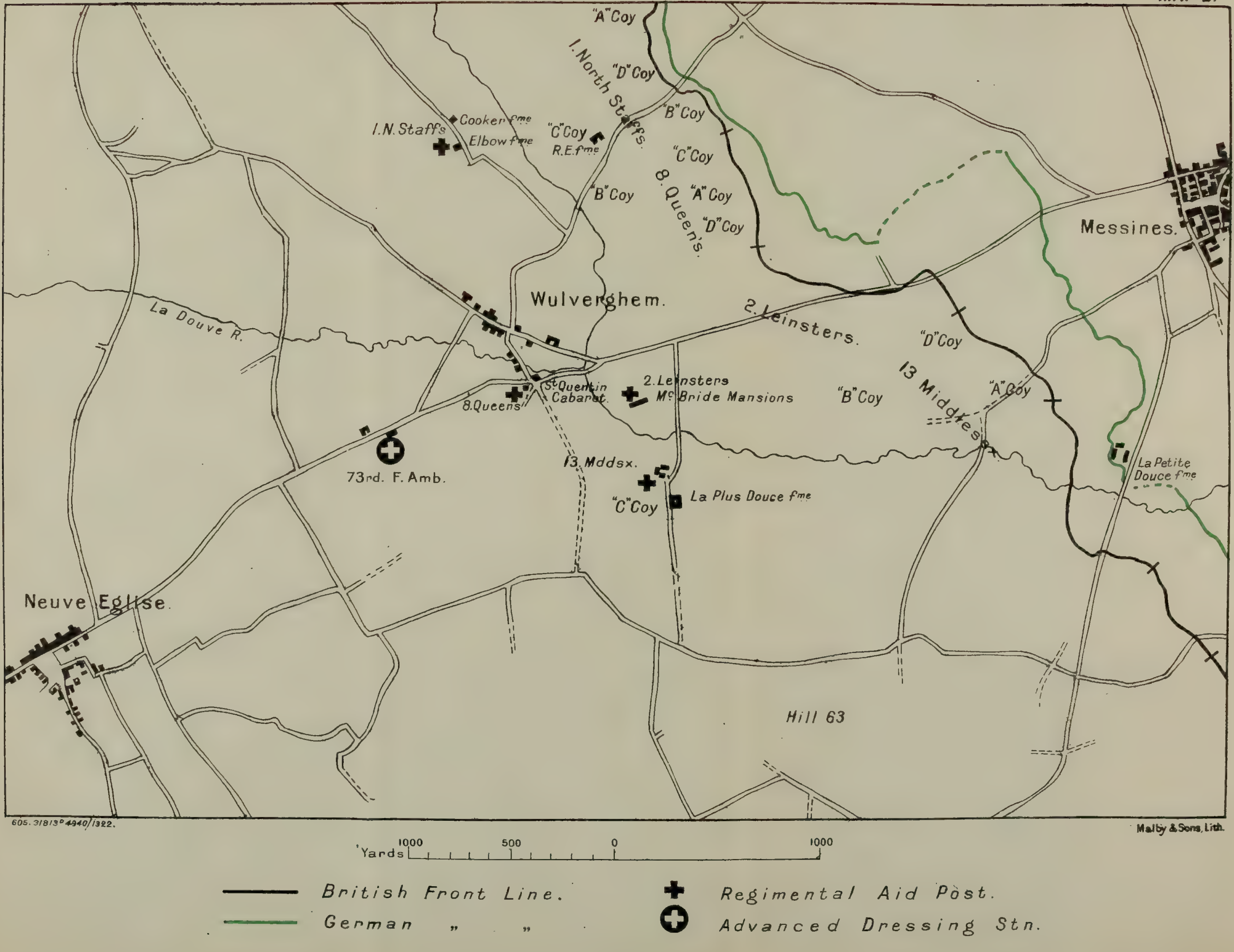
* The lines at the sides of Maps 1 and 2 are true North and South.

TABLE III.

Unit.	Coy.	Location.	Distance from Enemy in yards	No. of Gas Casualties	Location of Casualties
1st. N. Staffs...	A	Left	50	33	Nearly all in fire trench.
	D	Centre	100–120 ..	13	Fire trench.
	B	Right	50–105 ..	31	Fire trench.
	C	Support	400	17	At R.E.farm
			Unrecorded..	18	
			Total ..	112 = 19 per cent. of strength (approx.)	
8th Queen's ..	C	Left	130–220 ..	25	Fire trench.
	A	Centre	210–220 ..	37	Fire trench.
	D	Right	330	19	Fire trench.
	B	Support	1,500 to nearest enemy trench N.E.	14	Near St. Quentin Cabaret. Two platoons sent up to front trench.
			Unrecorded..	27	
			Total ..	122 = 24 per cent. of strength (approx.)	
2nd Leinsters..	A		200–300	3	Had time to put on helmets.
	B			3	
	C			1	
	D			10	
			Unrecorded	4	
			Total ..	21 = 3·5 per cent. of strength (approx.)	
13th Middlesex.	D	Left	320–500 ..	10	Fire trench.
	A	Right	320–500 ..	17	Fire trench.
	B	Support	.. .. ..	13	Close behind.
	C	Support	2,100 ..	9	About La Plus Douce Ferme.
			Unrecorded..	26	
			Total ..	75	

GERMAN CLOUD GAS ATTACK, APRIL 30TH 1916.

MAP 2.



605. 31813D 4940/1322.

Malby & Sons, Lith.

It is possible that the gas may have been strong enough to penetrate the helmets in some degree in the trenches nearest the point of emission of the gas, but there was no distinct evidence of this. The 10th Royal Welsh Fusiliers of the 76th Brigade only suffered 41 gas casualties (about 10 per cent. of their strength), with 5 casualties among R.E. and 5 among trench mortar personnel in their trenches, as compared with 112 casualties suffered by the 1st North Staffs and 122 by the 8th Queen's of the 72nd Brigade. The evidence pointed to the fact that the relatively small number of casualties suffered by the 10th Royal Welsh Fusiliers was due largely to the improved method of carrying the helmet, though at this point of the line the gas blew sideways, and only the front line, which was in places but 40 yds. from the opposing trenches, was badly affected.

The returns from battalions, field ambulances and casualty clearing stations showed that the total gas casualties on this occasion were 512, this figure including casualties suffered by other infantry battalions on the flanks of those already mentioned or in reserve, as well as by divisional and corps troops. The five battalions actually holding the line in the sector attacked (exclusive of machine gun, R.E., tunnelling company, or trench mortar personnel) furnished 371 gas casualties, or 73 per cent. of the total number. Many casualties also resulted from the heavy shell fire.

The regimental aid post of the 10th Royal Welsh Fusiliers was about 600 yds. behind the front line, and the position of the regimental aid posts of the battalions of the 72nd and 73rd Brigades is shown in Map 2. The main dressing station of No. 7 Field Ambulance (3rd Division) was at Locre Hospice, and the advanced dressing station of this unit was situated at Lindenhoek (see Map 1). This field ambulance admitted casualties mainly from the sector held by the 10th Royal Welsh Fusiliers. Practically the whole of the casualties from the 72nd and 73rd Brigades passed through No. 73 Field Ambulance (24th Division), which had its main dressing station at Dranoutre, with an advanced dressing station in a farm on the south side of the Wulverghem-Neuve Eglise road close to Wulverghem. Dranoutre lay just outside the area traversed by the gas, but the advanced dressing station at Wulverghem, about 2,000 yds. from the front line, lay right in the course of the gas cloud. The entrances to this dressing station were, however, well protected by anti-gas curtains, and the gas failed to penetrate, the occupants being able to carry on their work without helmets. No. 74 Field Ambulance (24th Division) had an advanced dressing station at Hyde Park Corner on the northern edge of Ploegsteert Wood, and a main dressing station farther to the south-west at Le Romarin, and dealt with a few casualties.

The aid post of the 1st North Staffs was set on fire early in the attack by shell fire, and was completely burnt out. The regimental aid posts were practically clear of the first main rush of cases by 10 a.m., though many slight gas casualties continued to report throughout the twenty-four hours succeeding the attack, and even in the next few days a few further cases reported with symptoms of bronchitis which were attributed by the medical officers to the effects of gassing. Casualties were evacuated as soon as possible from the aid posts to the field ambulances, the severe cases being sent on before the mild ones ; this was, however, necessarily a slow process, as all men who appeared to be suffering from the effects of gas had to be treated as lying cases and carried down on hand or wheeled stretchers.

Cases admitted to the advanced dressing station at Lindenhoek were evacuated by car as quickly as possible to the main dressing station at Locre Hospice, the journey only taking about half an hour. Some of these cases arrived at Locre within three hours of the gas attack. At Locre Hospice all cases were detained for several hours until some improvement set in, and the lighter cases were sent on to the casualty clearing stations first. Some of the worst cases were deliberately retained for treatment so as to spare them the harmful effects of a further journey, for this unit happened to have exceptionally good accommodation for this purpose in the shape of a large ward with beds.

The bulk of the casualties passed through the advanced dressing station near Wulverghem to the main dressing station of No. 73 Field Ambulance at Dranoutre. There was little suitable accommodation for severe casualties at Dranoutre, and the cases were evacuated as soon as possible to the casualty clearing stations in Bailleul. The more severe casualties were evacuated before the lighter ones from both Wulverghem and Dranoutre. By noon of 30th April, 143 gas casualties were admitted at Dranoutre, 176 in the next twenty-four hours, 11 in the next twenty-four hours, 12 in the next twenty-four hours and 10 more in the following four days, the last chiefly with symptoms of bronchitis.

No. 1 Canadian Casualty Clearing Station in the Asylum at Bailleul began to admit casualties from the field ambulances about 4 a.m. on 30th April and by 8.30 a.m. had admitted 72 cases. Then No. 8 Casualty Clearing Station, Bailleul, began to take in, and by 12.30 a.m. on 1st May this unit had admitted 321 gas casualties and was quite full, later arrivals being switched on to No. 2 Casualty Clearing Station, Bailleul, which admitted 81 cases in all.

With regard to the clinical symptoms, those most severely affected showed intense cyanosis and frothy exudation from the mouth and nose, though some of the severe casualties who reached the casualty clearing stations exhibited the pallor and collapse associated more particularly with phosgene poisoning ; in a few cases cyanosis gave place to pallor before death. Those who died rapidly in the trenches—the earliest deaths occurred about an hour and a half after the attack began—invariably showed deep cyanosis and copious frothing. Paroxysmal coughing, too, was a prominent feature in the early stages. The clinical evidence therefore suggested that the gas cloud did not in this instance contain a very high proportion of phosgene to chlorine. Data regarding the mortality amongst the gas casualties on this occasion are given below in conjunction with similar information about the other cloud attacks.

A number of civilians were living in the area traversed by the gas cloud, and about twenty of these were affected by the gas, though none fortunately very severely. These civilians, who had been instructed what to do in the event of a gas attack and had been furnished with respirators, protected themselves by closing the windows and doors of their houses and filling up all apertures through which gas might penetrate with wet cloths, and in many cases they wore anti-gas helmets. It speaks well for the speed with which the alarm was propagated that the civilians were able to escape so lightly, for many were in areas in which the gas cloud was in great concentration, some even as far east as Neuve Eglise.

The total gas casualties from cloud gas attacks between 19th December, 1915, and 8th August, 1916, are given in Table IV. It has been necessary to combine the attacks on 27th and 29th April, 1916, on the Hulluch sector in this table as

TABLE IV.

Date.	Total Gas Casualties.	Total Deaths from Gas Poisoning in France.	Deaths per 100 Casualties.
19.12.15	1,069	120	11·2
27.4.16 29.4.16 }	1,260	338	26·8
30.4.16	512	89	17·4
17.6.16	562	95	17·0
8.8.16	804	371	46·2
Total	4,207	1,013	24·0

it is impossible to differentiate with certainty the deaths in the trenches on the two occasions. The returns of the casualty clearing stations show, however, that of 987 gas casualties admitted from these two attacks 377 were caused on 27th April and 610 on 29th April, and one may therefore fairly assume that of the total casualties suffered in the two attacks three-fifths occurred on 29th April.

It will be seen that the cloud attacks of 27th and 29th April and of 8th August, 1916, are characterized by a much higher mortality amongst the gas casualties than was the case in the other attacks. The evidence points to the fact that the anti-gas discipline of the division that bore the brunt of the attacks on the first two dates was by no means perfect. Gas was known to be installed opposite its sector, and the " gas alert " had been ordered as soon as the wind moved to a dangerous quarter. On 27th April the first cloud liberated consisted mainly of smoke, and when the real gas attack developed an hour and a half later it appears to have caught the troops unawares. Many of the men mislaid their protective helmets after the first cloud had passed, and the bulk of the casualties occurred as a result of the second of these two clouds. On 8th August, 1916, the gas attack was made at a very inopportune moment. Reliefs were taking place in one of the divisions concerned, and the trenches were therefore abnormally crowded with men at the moment when the gas was liberated, the congestion interfering greatly with the rapid adjustment of the helmets. In addition to this many of the battalions in the sector had but recently arrived from the Somme battle front, and their ranks contained a large proportion of fresh drafts which had just come up from the base; these drafts had of course been trained in protective measures, but they still lacked the actual experience of gas in the field. These two instances show clearly how much depends in attacks of this kind on the anti-gas discipline and organization of the troops.

It is probable that the fabric helmets sometimes allowed a certain amount of gas to pass through in places where the opposing lines were very close together, for the absorbing power of the helmet was inferior to that of the box respirators, and cases of slight poisoning may have resulted from this. In a few cases there is reason to think that enough gas penetrated the helmet in these circumstances to cause the death of the wearer; thus in the cloud attack of 29th April, 1916, nearly every man was killed in the trench known as " The Kink," 50 yards from the point of emission of the gas, though it was reported that the bodies were found with helmets properly adjusted. Instances were not lacking in which men, either experiencing some slight irritation of the eyes or lungs owing to a little gas penetrating the helmet, or under the misapprehension that the smell of the chemicals with which the fabric was treated signified that the helmet was defective and admitting gas, tore off their helmets and fell victims to the cloud. With these few exceptions, however, it can be said with confidence that the casualties only occurred amongst men who for one reason or another failed to get on their helmets and adjust them properly before the gas enveloped them, or who removed them too early.

In all cases the heaviest incidence of casualties and the highest mortality were found at those points of the front line which were nearest to the enemy's trenches. In the description of the attack of 30th April, 1916, it has been shown that the main effect of the gas cloud was felt in the battalions actually holding the line in the sector affected, since when dealing with troops versed in anti-gas defence everything depends on surprise. The same holds good in the case of the other attacks. Thus on 27th and 29th April, 1916, the battalions mainly responsible for holding the line at the time suffered the following casualties: 7th Royal Irish Fusiliers, 80 gas casualties; 7th Royal Enniskillen Fusiliers, 263 gas casualties; 8th Royal Enniskillen Fusiliers, 366 gas casualties (about 73 per cent. of their strength); 8th Royal Dublin Fusiliers, 385 gas casualties and wounded (about 50 per cent of their strength), about two-thirds of the casualties being due to gas. These four battalions, therefore, furnished more than 900 of the known total of 1,260 gas casualties. In the attack of 8th August, 1916, practically the whole of the 804 gas casualties were derived from four battalions actually holding the sector.

It will be seen that almost half the total number of deaths took place in the trenches or in the regimental aid posts before the casualties could be evacuated to a medical unit. This is only what one might expect in attacks of this kind, owing to the rapidity with which a fatal pulmonary œdema may ensue after a very heavy dose of an acute lung irritant gas. Field ambulances as a rule did not have suitable accommodation for retaining the cases for treatment, and evacuated them to the casualty clearing stations as soon as possible, and in consequence of this the case mortality at the latter was the higher.

The different places at which casualties resulting from these cloud attacks died is shown in Table V.

TABLE V.

Places at which Gas Casualties died in France.

Date.	Number of Deaths.			
	Trenches or Regimental Aid Posts.	After Admission to Medical Units.		
		Field Ambulances.	Casualty Clearing Stations.	L. of C. Hospitals.
19.12.15	50	6	36	28
27. 4.16 29. 4.16 }	226	47	64	1
30. 4.16	25	13	50	1
17. 6.16	11	18	64	2
8. 8.16	173	91	106	1
Total	485	175	320	33
Percentage of total deaths	47·8	17·3	31·6	3·3

It will be noted that the mortality amongst gas casualties evacuated to hospitals on the lines of communication was considerable after the attack on 19th December, 1915, but negligible after the subsequent attacks. In the gas attacks of the spring of 1915 the fighting had been so severe, and the stress on the medical units so great, that many of the features of gas poisoning had not been properly appreciated. After the attack of 19th December, 1915, some of the gas casualties evacuated from the casualty clearing stations were in a moribund condition when the ambulance trains reached the base, and enquiry soon brought to light the fact that pulmonary œdema resulting from exposure to warfare gas of the acute lung irritant type might have an insidious onset, and thus lead the gravity of a case to be underestimated in the earlier stages. It was in this gas attack that instances of the delayed onset of acute pulmonary œdema after exposure to warfare gas were first clearly identified. There was every reason to think that the extra fatigue and disturbance entailed by transport would act prejudicially in these cases, and the D.G.M.S. therefore issued orders on 10th February, 1916, that every casualty clearing station was to retain cases showing definite clinical evidence of gas poisoning until confidence could be felt that the patients could travel safely. After this date the only deaths at the base attributable to poisoning with an acute lung irritant gas were the result of secondary broncho-pneumonia, and the figures indicate how infrequently this complication occurred.

The casualties that died in the trenches or regimental aid posts may be regarded as having been killed outright on the field by gas, and if these are excluded for the moment and attention directed to those casualties that survived long enough to be evacuated to field ambulances, casualty clearing stations, and hospitals on the lines of communication, it will be found that the mortality showed a steady increase in the successive attacks. This is shown in Table VI.

TABLE VI.

Mortality amongst Cloud Gas Casualties admitted to Medical Units.

	Date of Attack.				
	19.12.15	27.4.16 29.4.16	30.4.16	17.6.16	8.8.16
Admissions	1,019	1,034	487	551	631
Deaths	70	112	64	84	198
Deaths per 100 admissions	6·9	10·8	11·1	15·2	31·4

It has been pointed out that the policy of the enemy during the period under review was to increase the concentration and the toxicity of the gas clouds, and it is probable that this factor was mainly responsible for the increasing severity of the gas casualties admitted to medical units, since any man who got gassed at all was likely to be severely affected, though improvement in the general anti-gas discipline of the troops would naturally tend to reduce the total number of casualties. The experience gained in these gas attacks naturally led to improvement in the methods of dealing with the heavy influx of gas casualties, and this ensured more rapid transport of the cases back to the casualty clearing stations. There is little doubt that as a result of this a certain number of casualties were brought back in the later attacks to medical units, and died there, who would in the earlier attacks have succumbed on the field. The only attack in which rapid evacuation of the casualties was interfered with was that of 19th December, 1915, for as the attack was made just before dawn in the Ypres salient the evacuation of all but the lightest cases had to be postponed till darkness, and consequently it was not till twelve hours had elapsed that cases began to reach the casualty clearing stations at Rémy Siding, near Poperinghe, in any numbers. On 8th August, 1916, the sector of attack was practically the same, but as the gas was liberated at an early hour of the night it was possible to evacuate the bulk of the cases before dawn.

" Lethal " Gas Shell Period, July 1916 *to July* 1917.

The Germans could only count on a favourable wind for a few weeks in the spring, and this limited their chance of making successful cloud gas attacks. It was therefore necessary for them to devise some other means for liberating gas on a large scale if they were to obtain full advantage from the start they had gained in gas warfare, and since June 1915 they had turned their attention seriously to the employment in projectiles of poisonous substances capable of exerting a lethal action.

" K " shell containing chlormethyl-chloroformate had been introduced by the Germans on the British front at the time of the cloud gas attack of 19th December, 1915, and they were occasionally used, though only in small numbers, during the first half of 1916. Though chlormethyl-chloroformate is a definite acute lung irritant, its toxicity is comparatively low, and the few " K " shell that were used did little harm, though occasional reports of the use of gas shell which, on bursting, caused a choking sensation and a feeling of tightness on the chest without marked lachrymation pointed to their employment.

A large supply of " K " and of " C " or " K2 " shell was assured by the end of June, 1916, and very soon after the first battle of the Somme commenced these shell began to be used in great numbers, the first serious bombardment occurring on the night of 14th–15th July. From this date onwards the Germans placed more and more reliance on heavy gas shell bombardments. The " C " or " K2 " shell, which carried the distinctive mark of a green cross, and contained trichlormethyl-chloroformate, a powerful lung irritant substance closely resembling phosgene in its physiological properties, and possessing quite strong lachrymatory power, were far more dangerous than the " K " shell, and soon displaced the latter altogether. A little later on the same filling began to be used in Minenwerfer bombs " Lethal " shell had but a small bursting charge, less in fact than was usual in the lachrymatory shell to which the troops had by this time become accustomed. At first the trifling report made by the explosion of these shell misled them into thinking that the shell were blinds, and until experience was gained a number of small groups of severe casualties resulted owing to men omitting to put on their protective helmets as soon as the shell began to fall near them and thus being caught by the gas before they could appreciate what they had to deal with.

In November 1916 Minenwerfer bombs filled with phosgene (" D-Stoff ") began to come into use, and in April 1917 gas shells filled with a mixture of trichlormethyl-chloroformate and chloropicrin (Green Cross 1 shell), made their appearance. The " P H " helmets were incapable of absorbing chloropicrin, but the general issue of the small box respirator, which afforded a high degree of protection against this as well as other warfare gases, had been begun in August 1916 and was completed early in 1917.

There is no doubt that the Germans overestimated the effectiveness of their lethal shell during this period, for they made the mistake of distributing their fire over wide areas instead of concentrating surprise bombardments on important targets, the only method which might have enabled them to make the shell effective agents for causing casualties. The consequence was that though the great numbers of gas shell that were employed caused considerable annoyance as harassing agents, the number of actual casualties that resulted from their use was small, and the fact that this period of the war includes the first battle of the Somme, the battle of Arras, and the capture of the Messines Ridge, times, that is, when the concentration of troops in preparation for the attacks furnished particularly favourable targets, emphasizes the relative ineffectiveness of these shell.

The weekly returns of the D.G.M.S., showing the total number of gas-shell casualties admitted to casualty clearing stations and the deaths that occurred from gas poisoning in these units and in field ambulances, are given in Table VII.

These figures as they stand somewhat underestimate the total casualties from gas shell during this period, but the omissions amount to but an insignificant fraction of the whole, so that the table suffices to give a very reasonable idea of the losses. The number of deaths from gas shell poisoning that took place either in the trenches or in hospitals on the lines of communication is not given in the table. The number

TABLE VII.

Gas Shell Casualties admitted to Casualty Clearing Stations, and Deaths from Gas Shell Poisoning in Field Ambulances and Casualty Clearing Stations, from the first use of "Lethal" Gas Shell on 14th–15th July, 1916, to the Introduction of Mustard Gas.

Week ending.	Total Casualties.	Deaths.	For Periods of Four Weeks.			Battle.
			Total Casualties.	Deaths.	Deaths per 100 Casualties.	
1916—						
21st July	335	36	1,465	104	7·1	Somme, 1.7.16
29th ,,	694	40				
7th Aug.	387	14				
12th ,,	49	14				
19th ,,	47	1	1,049	35	3·3	
26th ,,	87	1				
2nd Sept.	540	14				
9th ,,	375	19				
16th ,,	128	10	345	25	7·3	
23rd ,,	86	1				
30th ,,	86	10				
7th Oct.	45	4				
14th ,,	46	1	225	33	14·7	
21st ,,	29	2				
28th ,,	98	19				
4th Nov.	52	11				
11th ,,	26	2	343	26	7·6	
18th ,,	270	18				
25th ,,	18	1				
2nd Dec.	29	5				
9th ,,	12	1	133	7	5·3	
16th ,,	5	–				
23rd ,,	1	–				
31st ,,	115	6				
1917—						
7th Jan.	41	–	159	14	8·8	
14th ,,	55	3				
21st ,,	23	4				
28th ,,	40	7				
3rd Feb.	25	4	351	36	10·3	
10th ,,	33	1				
17th ,,	196	21				
24th ,,	97	10				
3rd Mar.	110	6	407	25	6·1	
10th ,,	128	10				
17th ,,	144	8				
24th ,,	25	1				

TABLE VII—*cont.*

Week ending.	Total Casualties.	Deaths.	For Periods of Four Weeks.			Battle.
			Total Casualties.	Deaths.	Deaths per 100 Casualties.	
31st Mar.	13	–	348	34	9·8	Arras, 9.4.17
7th Apr.	87	15				
14th ,,	146	14				
21st ,,	102	5				
28th ,,	282	9	1,169	43	3·7	
5th May	390	10				
12th ,,	293	10				
19th ,,	204	14				
26th ,,	153	4	1,616	57	3·5	Messines, 7.6.17
2nd June	341	9				
9th ,,	826	31				
16th ,,	296	13				
23rd ,,	351	34	1,196	93	7·8	
30th ,,	417	20				
7th July	194	7				
13th ,,	234	32				
Total....	8,806	532	8,806	532	6·0	

of deaths in the trenches was not large, so far as can be ascertained ; it was certainly far lower in proportion to total deaths than was the case in the cloud gas attacks. Gas shell bombardments were frequently directed on targets behind the trench system, such as batteries, roads, or billets, places from which rapid evacuation of casualties to medical units was an easy problem in comparison with the difficult task of removing casualties from the trenches in the cloud gas attacks, especially as the number of cases that had to be dealt with at any one time was far less than was the case in the cloud gas attacks. The instructions regarding the evacuation of severe cases of cloud gas poisoning from medical units in army areas to the lines of communication held good for cases of poisoning caused by acute lung irritant substances contained in shells, and the deaths that occurred in hospitals on the lines of communication may therefore be regarded as a negligible quantity. Another source of error is due to the fact that the table gives no indication of the number of slight cases of poisoning that may have been detained by field ambulances till fit to rejoin their units, though this number cannot have been great.

The figures shown in Table VII include casualties caused by ordinary lachrymator shell as well as those due to " lethal " or " Green Cross " shell, so far as such cases reached the casualty clearing stations. There were relatively few of these casualties, and as there was no mortality amongst them the whole of the deaths recorded in the table are to be ascribed to the gas shell containing acute lung irritants.

The returns upon which Table VII is based do not show the date on which fatal cases were gassed, and the deaths in any one week do not, therefore, necessarily correspond with the admissions during the same week. At the same time, nearly all the deaths caused by the acute lung irritants occur within three days of exposure, in fact, 80 per cent. occur in the first twenty-four hours, and by averaging the figures for a few consecutive weeks the error due to this cause is diminished, and a reasonable estimate of the true mortality can be obtained. The case mortality is, therefore, only calculated in Table VII from the total casualties and deaths occurring in four-weekly periods. The average mortality amongst the gas shell casualties is evidently much lower than amongst the casualties resulting from the cloud gas attacks, and the reason for this is clear, for the essential element of surprise, coupled with a heavy concentration of gas, could not be obtained over a given area by gas shell to anything like the extent that was possible with the cloud attack or the projector discharge which came into use at a later date. In many cases the only severe casualties resulting from heavy artillery or trench mortar bombardments with shell containing acute lung irritant substances occurred right at the commencement of the shelling, men being caught unawares by shell bursting close to them before they had time to appreciate the nature of the bombardment and put on their respirators.

Reference to Tables IV and VII will show that during the twelve months from July 1916 to July 1917, the British troops only suffered about twice as many casualties and half as many deaths from gas shell as were caused by the six cloud gas attacks between December 1915 and August 1916.

The Mustard Gas Period, July 1917 *to November* 1918.

On the night of the 10th–11th July, 1917, a gas shell bombardment was reported in the Nieuport sector in which shell containing trichlormethyl-chloroformate and a few lachrymatory shell were accompanied by shell which burst with a loud report like H.E. shell, but caused sneezing, slight irritation of the nose and eyes, and tightness of the chest. No blind shell could be obtained, and it was uncertain whether or not a new type of gas shell had been introduced by the Germans. Before anything definite could be ascertained a far more serious problem had arisen.

On the night of 12th–13th July, 1917, Ypres and the neighbourhood were subjected to an intense bombardment with gas shell of a type entirely different from anything that had been used up to that date. These were mainly of 77 mm. and 105 mm. calibre, marked on the base or side with a yellow cross, and containing a liquid which was identified in a few days as $\beta\beta$-dichlor-ethyl-sulphide, a substance which was to prove far the most effective poison introduced during the war. The vapour which arose when the shell burst had no immediate irritant action on the eyes or chest, and it had only a slight smell resembling mustard or garlic, which gave origin to the name " mustard gas," though the substance was not related chemically to the true mustard oils. The French always spoke of this substance as yperite, the name being derived from the sector where it was first used. The troops naturally tended to underestimate the danger, for up to this date they had been accustomed to associate " gas " with violent irritant or choking sensations, and many, under the impression that the gas was not strong enough to hurt them, omitted to wear their helmets or to keep them on for long enough, nor did they as yet grasp that the ground in the vicinity of a burst was heavily contaminated by the poison and continued to be a source of danger long after the bombardment had ceased.

At first the troops in the bombarded area suffered little or no discomfort from the gas save for slight irritation of the nose, which caused sneezing, but in the course of an hour or two the typical signs of mustard gas poisoning began to appear in the shape of painful inflammation of the eyes and vomiting, followed by reddening of the skin and blistering, and casualties began to come back to the field ambulances in great numbers. The conjunctivitis developed rapidly, and by the time the cases reached the casualty clearing stations they were virtually blind and had to be led about in files, each man holding on to the man in front, with an orderly or a lightly wounded man whose vision was unimpaired guiding the leader. In the first few hours the relative slightness of pulmonary symptoms formed a strong contrast to the grave condition of pulmonary œdema shown by casualties acutely affected by the lung irritant gases. One or two cases had been admitted to the casualty clearing stations with symptoms suggestive of acute pulmonary œdema, as well as with inflammation of the eyes and skin, but, as shell containing trichlormethyl-chloroformate had been used during the bombardment, as well as the Yellow Cross shell, it seemed not unlikely that the effects of the lung irritant gas might here be superimposed on those of mustard gas, especially as there were a few cases of pure œdema of the lungs uncomplicated by symptoms of mustard gas poisoning. The first autopsy made on one of these cases which terminated fatally established, however, the true nature of the violent inflammatory action of mustard gas on the trachea and bronchial tubes, and the essential difference from the action of the acute lung irritants. The great majority of the cases showed little distress in their breathing at first, though a husky voice and a hard cough often showed that the respiratory system was not unaffected. After the lapse of a few more hours symptoms of laryngitis, tracheitis, and bronchitis became quite definite in a large number of the casualties, and some of these later developed grave or fatal broncho-pneumonia. The great delay in the onset of really serious symptoms was strikingly different from what was seen in poisoning by an acute lung irritant gas.

The data shown in Table VIII have been taken from the records of the principal casualty clearing stations which dealt with the mustard gas casualties resulting from the first bombardment with Yellow Cross shell at Ypres, so that the general effects of this bombardment may be compared with the effects of a cloud gas attack.

TABLE VIII.

Mustard Gas Casualties in July 1917.

Unit.	Number of Admissions, 13th and 14th July.	Evacuated to Corps Rest Station by 17th July.	Evacuated to L. of C. by 17th July.	Approximate Number seriously Ill from Pulmonary Trouble.	Deaths.		
					13th–17th July.	18th–19th July.	20th–28th July.
No. 47 C.C.S.	799	412	99	120	27	12	21
No. 61 C.C.S.	296	164	36	45	2	2	4
No. 46 C.C.S.	826	388	—	100	9	3	5
No. 64 C.C.S.	222	—	—	1	1*	—	—
Total	2,143			266	39	17	30

* Probably due to an acute lung irritant.

Ten further deaths occurred after evacuation to the lines of communication, so that of the total of 2,143 cases admitted to these four units 95 died, exclusive of the doubtful case of death from a lung irritant gas, giving a mortality of 4·4 per cent. About 12½ per cent. of the admissions were classed as serious, and about one-third of these serious cases died.

The Ypres area was shelled with mustard gas almost every night until the end of the month. On the night of 21st–22nd July a heavy bombardment with Yellow Cross shell was directed on Nieuport, which again led to a heavy toll of casualties; these were on the whole of a more serious character than those resulting from the first mustard gas bombardment at Ypres. The bombardment at Ypres had come as a complete surprise, and that at Nieuport was nearly as great a surprise, for the troops had not yet received adequate warning and instructions regarding the new gas. The Nieuport sector had only recently been taken over by the British, and some of the casualty clearing stations had only just arrived and were not yet in full working order. Evacuation to the lines of communication had of necessity to be accelerated so as to avoid undue congestion in the army area, and consequently the proportion of severe cases which reached the base on this occasion was high and the mortality in the hospitals on the lines of communication accentuated.

Armentières was shelled with mustard gas on the night of 20th–21st July, and on 28th–29th July heavy Yellow Cross bombardments were directed on both Armentières and Nieuport. The second of these bombardments of Armentières led to 675 casualties amongst the civilian population who still continued to inhabit the town, and 86 of these casualties had died by 18th August, the high mortality being due in part to the number of aged persons affected, and in part to the difficulty experienced by the inhabitants in leaving the shelter of cellars, etc., and getting away from the bombarded area while the shelling was in progress, and to their reluctance to vacate their homes.

From now on Yellow Cross shells were used by the Germans in enormous numbers, and it was only in the winter of 1917–1918 and in June and July 1918, during the lull between the German and Allied offensives, that gas shelling of this type showed any marked reduction.

During the first three weeks of the mustard gas period 14,276 cases of gas shell poisoning were admitted to the casualty clearing stations and about 500 deaths occurred amongst these casualties. Of these, only 286 casualties with 17 deaths came from the Third Army, which had not as yet been subjected to Yellow Cross shelling, and the great bulk of both the casualties and deaths from the remaining armies were obviously attributable to mustard gas. In this brief period, therefore, the Yellow Cross shell had accounted for more casualties and practically as many deaths as the entire previous year's shelling with acute lung irritants. The returns from the Fifth Army which occupied the Ypres front are given for these three weeks in Table IX, to show how the casualty clearing stations as a whole were dealing with the gas shell casualties they had admitted.

TABLE IX.

Week ending.	Remaining from previous Week.	Admissions	Deaths.	Evacuated to		Returned to Duty.	Remaining at end of Period.
				L. of C.	Corps Rest Statn.		
1917.							
21st July	65	2,821	77	581	1,222	9	—
28th July	—	3,019	53	3,258	179	66	—
4th August	—	1,957	14	2,071	5	20	307
Total	65	7,797	144	5,910	1,406	95	307

These figures show how small was the number of casualties that were fit to be returned to duty in a few days. More than three-quarters of the cases admitted had to be transferred to hospitals on the lines of communication, a proportion which, as will be shown later, was maintained throughout the mustard gas period, for the length of time required for convalescence and the necessity of avoiding undue congestion of front areas precluded any but the mildest cases from being retained in casualty clearing stations or corps rest stations till recovery was complete.

Early in August 1917, blind shell with the distinctive marking of a blue cross were obtained. The filling of these consisted of a large H.E. charge in the middle of which was embedded a glass bottle containing diphenyl-chlorarsine, and investigation of the physiological properties of this substance at once afforded the clue to the origin of the nasal irritation and sneezing which had characterized the H.E. bombardment of 10th–11th July, and the subsequent mustard gas bombardments. About the same time shell marked with a green cross (Green Cross 2 shell), containing diphenyl-chlorarsine mixed with trichlormethyl-chloroformate and phosgene, were identified.

Throughout the mustard gas period bombardments with mixed gas shell, or with gas and H.E. shell, were the rule, and it was only rarely that a bombardment consisted solely of a single type of gas shell. The chlorarsine compounds were introduced by the Germans in the belief that they would penetrate the British respirator, and cause such immediate irritation that the affected man would not only be temporarily incapacitated but would be unable to tolerate his respirator and would thus become susceptible to the more lethal gases. The fact that stannic chloride, which the British had now been using for some time in gas shells, was not completely stopped by the original small box respirator had, however, suggested the necessity for adding to it some means for filtering particulate matter from the air. At first, in April 1917, this took the form of an additional extension containing cotton-wool which could be fixed to the bottom of the original canister, but by the end of the year all the canisters of this type had been replaced by a new form which included the filtering medium. The canisters fitted with the extension, as well as the later and more perfect form, gave complete protection against the concentrations of the chlorarsines met with in the field. The hopes of the Germans were therefore falsified, and the fact that examination of captured box respirators soon led to their recognition of this is shown by a document issued by German general headquarters on 7th September, 1917, in which it is stated that as the box respirator gives protection against Blue Cross and Green Cross 2 shell, Blue Cross shell should be fired at the start of a gas shell bombardment, since they cannot be distinguished from H.E. shell until they have caused sneezing; Green Cross shell should be fired subsequently, as the sneezing may prevent the adjustment of the respirator. It was customary, therefore, to find Blue Cross shell used as a preliminary to a Green Cross bombardment or employed simultaneously with the latter shell, whilst H.E. shell or Blue Cross shell almost invariably accompanied Yellow Cross shell in a mustard gas bombardment, mainly with the idea that the noise of the explosions should hinder the Yellow Cross shell being recognized by their small burst.

Shell containing phenyl-carbylamine-chloride were introduced early in the mustard gas period and were used to a limited extent during the latter part of 1917 and throughout 1918.

The substance has an extremely nauseating odour as well as rather weak lachrymatory and lung irritant properties, but it proved quite ineffective in the field.

In September 1917 the Germans made use of a down-cast shaft in their lines to flood Fosse 8 in the Bêthune coal-field with chloropicrin vapour, and several men of a British patrol as well as some French miners who were in the pit at the time lost their lives. The incident has been related by Dale Logan.

Gas shelling was much below normal during December 1917 and January and February 1918. In January 1918 the occurrence of a few casualties showing more marked symptoms of the effects of diphenyl-chlorarsine than had been usual in 1917 suggested that the Germans were introducing a Blue Cross shell of improved design, or one perhaps containing another chlorarsine derivative, the symptoms pointing somewhat to the use of ethyl-dichlorarsine. It was not till March that this substance was definitely identified in gas shell marked with a yellow cross ; these were the shell designated Yellow Cross 1 by the Germans, but owing to the likelihood of confusing them with ordinary Yellow Cross shell containing mustard gas they were renamed Green Cross 3 in July 1918, and marked accordingly, since they were used tactically in the same circumstances as Green Cross 1 and 2 Sometimes Green Cross 3 shell contained ethyl-dibromarsine in addition to ethyl-dichlorarsine, and from June 1918 onwards Blue Cross shell often contained diphenyl-cyanarsine as well as diphenyl-chlorarsine, though the addition of these substances did not alter the effects of the shell appreciably.

In January 1918 a few definite instances were reported in which men were poisoned by washing in or drinking water contaminated with derivatives of the chlorarsines, the water having been obtained from shell craters in areas subjected to Blue Cross or Green Cross 3 shelling. Apart from this there was no definite evidence that casualties were caused by the consumption of food which had been exposed to gas. The general instructions regarding defence against gas ordered that all food and drinking water was to be kept covered, and that no food that had an unusual taste or odour after a gas attack or bombardment was to be eaten, while water obtained from shell craters was not to be used for drinking, cooking, or washing purposes.

In March 1918 the Germans used gas shell on a more extensive scale than in any previous period. On the night of

10th–11th March the villages and valleys in the Cambrai salient were subjected to an intense bombardment with Yellow Cross shell. This bombardment was repeated on the three succeeding nights, and it was estimated that altogether not less than 150,000 shell must have been fired into the area. About 4,500 casualties resulted from this bombardment, but they were of a much less severe type than those which occurred in the summer and autumn of 1917, actual blistering of the skin being uncommon and severe pulmonary trouble rare. The mortality amongst these casualties was little over 1 per cent. The casualties could all be traced to men omitting to take proper precautions to protect themselves, because they failed to appreciate that mustard gas, in spite of its slight smell and lack of immediate irritant action, was toxic in extremely low concentration and persisted for long on the ground in dangerous quantities.

Gas shell were used by the Germans in enormous numbers during the preliminary bombardment for their great offensive of 21st March, 1918 ; in fact, the proportion of gas shell was estimated at 25 per cent. of the total number of shell fired. On the front of attack only Green Cross or Blue Cross shell were used, but north of the Scarpe there were extensive gas shell bombardments in which Yellow Cross shell predominated. The gas shelling on the battle front ceased two or three hours before the infantry attack, but though the fatigue and discomfort caused by wearing respirators must have contributed in no small measure to the strain to which the troops were subjected during the intense bombardment, the casualties actually caused by the gas itself were disproportionately small considering the number of shell fired and the concentration of the troops.

The total gas shell casualties returned for the week ending 23rd March by the casualty clearing stations of the Third and Fifth Armies, who held the front against which the attack developed, amounted to 3,378, whilst the corresponding returns from the First and Second Armies, who held the line farther north and were subjected mainly to Yellow Cross shelling, showed 3,496 gas shell casualties ; but it must be remembered that the number of gas casualties who may have fallen into the hands of the enemy is not included in these figures. In the following week only 2,686 gas shell casualties were returned by the four armies. No infantry attack was made on the area in the Cambrai salient which had been so heavily shelled with mustard gas a few days previously.

The character of the gas shelling during March made it clear that the Germans had adopted a definite plan for the tactical use of gas, and this was substantiated by the capture of German documents and orders at a later date. As long ago as August 1915, orders issued by Falkenhayn had differentiated gas shell into two categories, the persistent type for harassing purposes, and the non-persistent type, which could be used before an infantry attack. Instructions for artillery gas shelling issued by the German General Staff on 1st December, 1917, divide gas shell into the following classes: (*a*) Green Cross, (*b*) Yellow Cross, (*c*) Yellow Cross 1, (*d*) Blue Cross, and (*e*) Yellow Cross H.E., and state that though Yellow Cross and Yellow Cross H.E. have great persistency and render it unsafe to occupy the shelled area for hours or even days, it is safe for troops to occupy ground which has been shelled by Green Cross within one or two hours after the cessation of the bombardment, while troops can safely follow up a Blue Cross bombardment immediately after the dissipation of the cloud. Further instructions issued from German general headquarters under Ludendorff's signature on 9th July, 1918, mention the following points. Green Cross has a rapid action and is an excellent harassing and neutralizing agent; it can be employed just before an offensive since it has a low persistency and the shelled area can be crossed by troops about two hours after the shoot. Yellow Cross 1 (now to be renamed Green Cross 3) is similar, but in many respects superior. Yellow Cross has a slow action and is stopped by the respirator, though clothing may be contaminated by splashes of the actual liquid. Its persistency is very great, especially in dry weather, and no area which it is desired to occupy must be shelled with Yellow Cross for the last two to four days preceding the attack, though even after that interval slight cases of poisoning may still occur. H.E. Yellow Cross affords a better dispersion of the poison and reduces the persistency. These instructions contain the following remarks on Blue Cross: "The substance in Blue Cross shell acts with extraordinary rapidity, in fact, almost instantaneously, but it generally puts troops out of action for only a short time. In sufficient concentrations it penetrates the French mask effectively and the English mask to a lesser degree, in which case it forces the enemy to tear off their masks. For this reason a mixture of Blue and Green Cross is recommended. In the case of an insufficient concentration Blue Cross at least forces the enemy to wear their masks, thereby interfering with their fighting efficiency. The effect of the gas passes away and rapidly disappears after the gas or detonation cloud. In consequence it can be employed when our infantry are relatively close to it."

In the period from March 1918 to the end of the war, which may be regarded as exhibiting the culmination of the German methods of gas warfare, the enemy therefore practically divided their various gas shell into but three classes—Green Cross, Blue Cross, and Yellow Cross. The two former, which showed little or no persistency, were to be used for general harassing or neutralizing purposes, or in the preliminary bombardment immediately before an attack. The use of Yellow Cross was to be restricted to areas which there was no intention of occupying, and where there was a likelihood of causing a number of casualties and rendering important points, such as battery positions, assembly points and billets, untenable by their opponents.

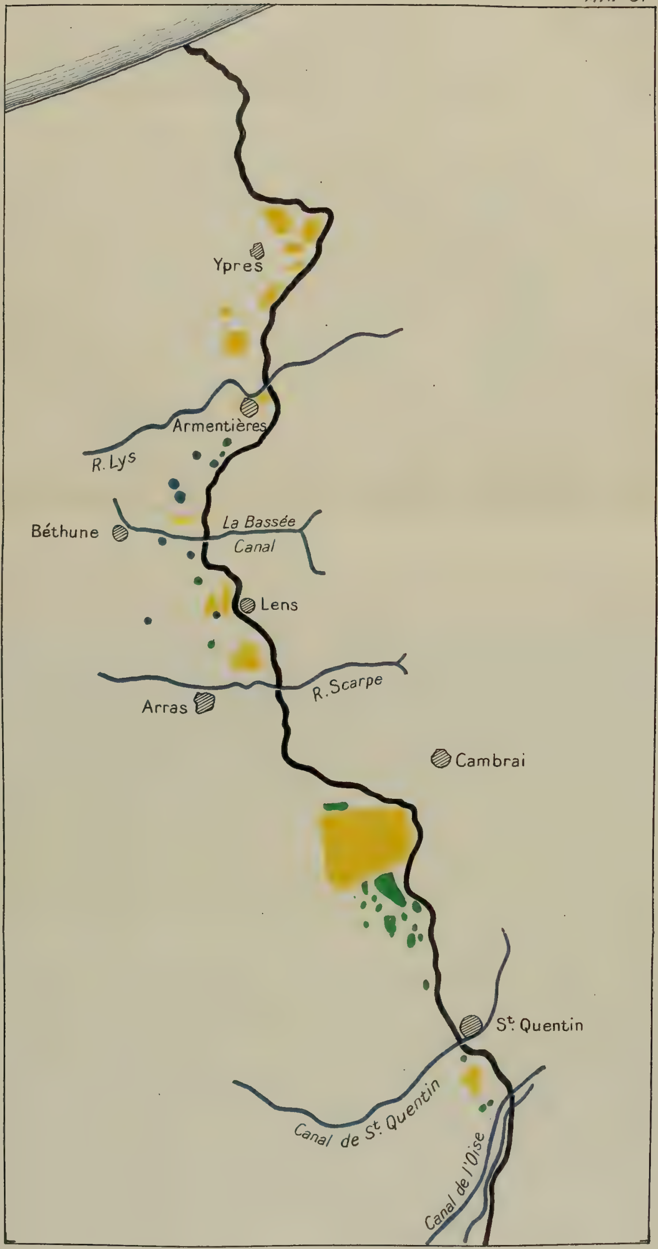
Maps 3 to 6 represent in semi-diagrammatic form the actual gas shelling on the British front on several different occasions to show how closely the Germans followed these instructions.

Map 3 shows the German gas shelling for the period 9th to 19th March, 1918. The intense Yellow Cross bombardments of the Cambrai salient stand out conspicuously, but with the exception of one limited area south of St. Quentin, which was shelled with Yellow Cross, Green Cross shell alone were employed on the rest of the front south of the Scarpe, though Yellow Cross was extensively used from the Scarpe northwards.

Map 4 shows the change that occurred as the German offensive of 21st March, 1918, opened. Green and Blue Cross were alone used on the battle front, no direct attack being made on the Cambrai salient, while shelling with all types of gas shell, particularly Yellow Cross, increased from the Scarpe to Ypres.

The gas shelling on 7th to 9th April, 1918, which immediately preceded the German offensive on the Lys front on 9th April, is shown in Map 5. No Yellow Cross shell were used on the front to be attacked, but heavy bombardments with this type of shell were put down on battery positions and villages south of the La Bassée Canal, while the Yellow Cross shelling of Armentières was so heavy that the gutters were reported as running with mustard gas, and it may be noticed that orders had been issued by the Germans that none of their troops were to enter the town for a fortnight. A considerable number

MAP 3.



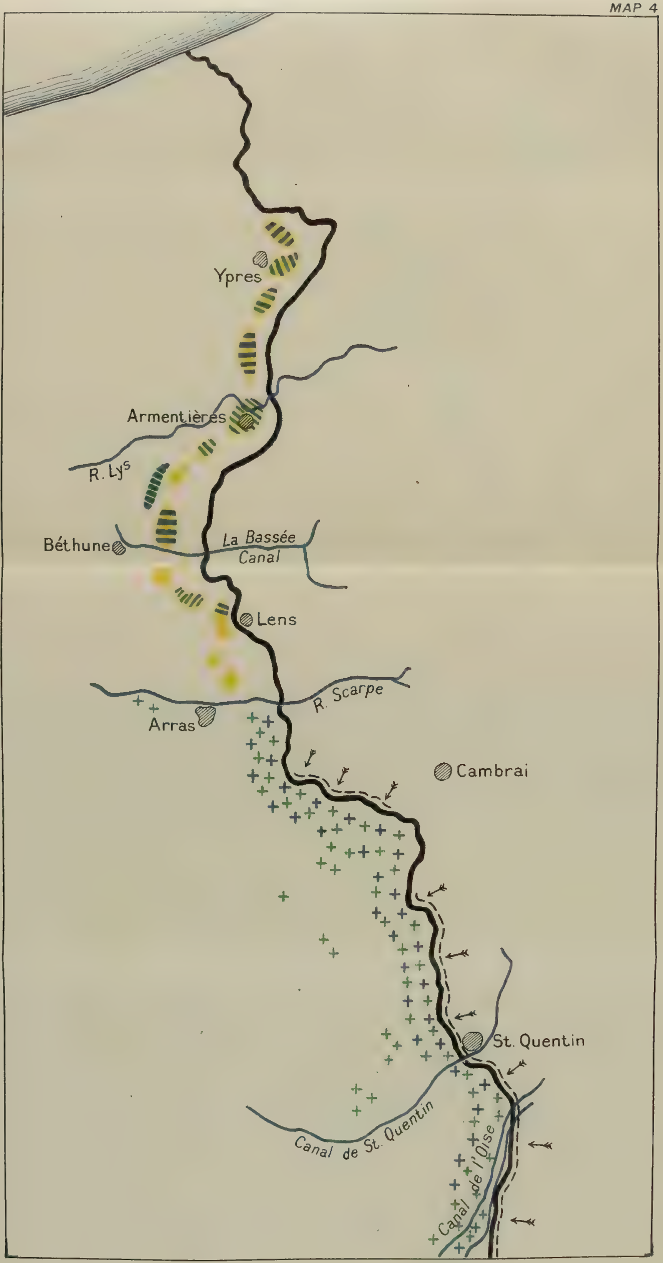
ENEMY GAS SHELL BOMBARDMENTS

FROM 9·3·18 TO 19·3·18.

605.31313^{D} 4940/1322.1500.8.22

Malby & Sons, Lith.

MAP 4

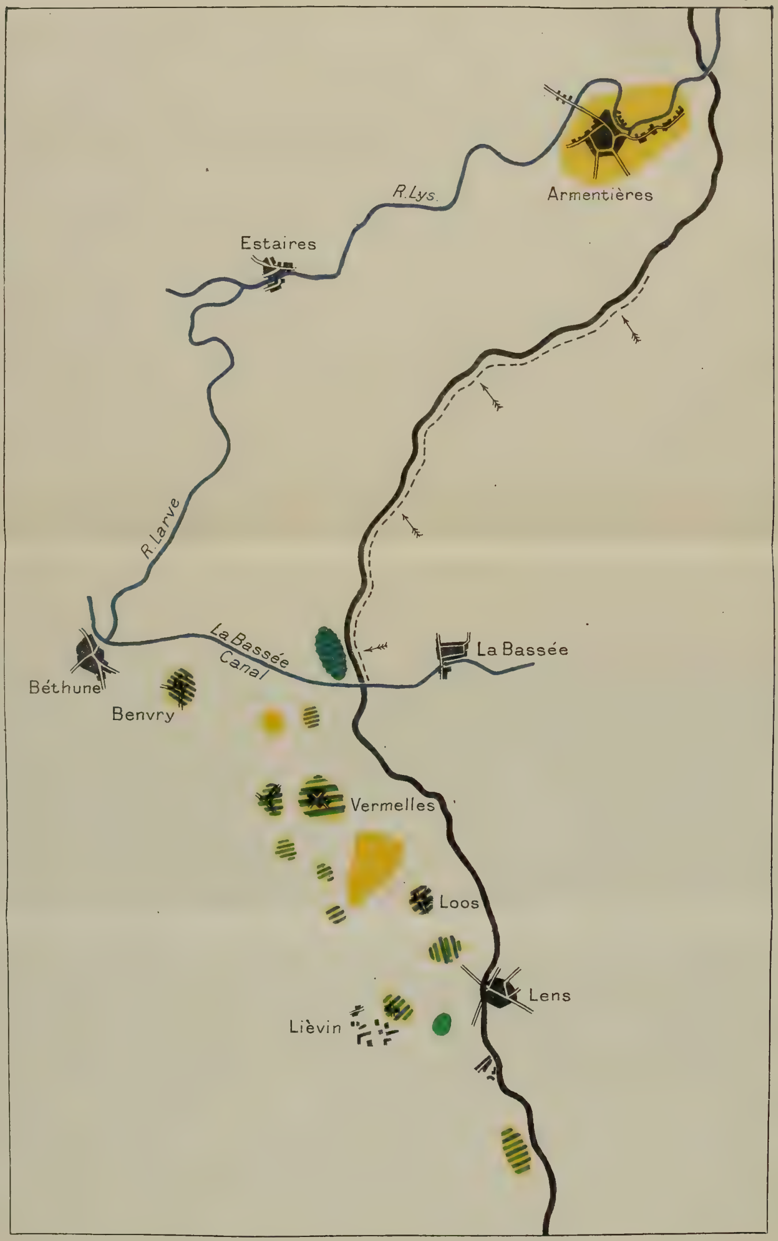


ENEMY GAS SHELL BOMBARDMENTS
MARCH 21, 1918.

605 31813⁹ 4940/1322

Malby & Sons, Lith

MAP 5.



ENEMY GAS SHELL BOMBARDMENTS.

APRIL 7 TO 9 1918.

605.31813º4940/1322
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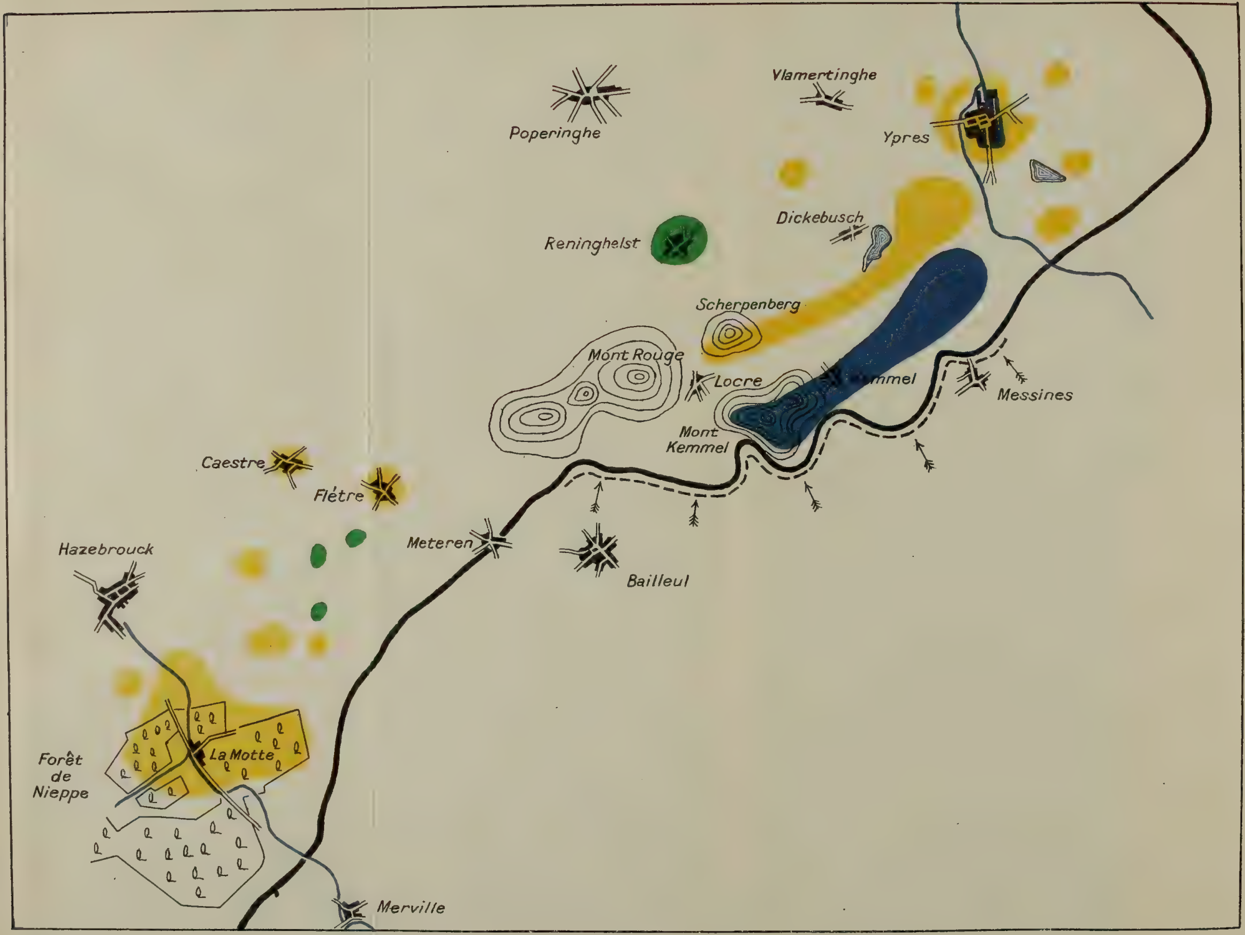
MAP 6.



ENEMY GAS SHELL BOMBARDMENTS
APRIL 20-25, 1918.

605.31813º 4940/1322

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of Green and Blue Cross shell was used on the actual front attacked as the offensive opened.

Map 6 shows the gas shelling in the few days preceding and including the German attack on Mont Kemmel on 25th April, 1918. In this case their objective was limited. The areas on the flanks of the proposed sector of attack were heavily shelled with Yellow Cross, and on the day of the attack an intense bombardment with Blue Cross and some Green Cross shell was opened on the front from Mont Kemmel to Voormezeele, while a Yellow Cross barrage was put down on the line running from Scherpenberg to Kruisstraathoek just beyond the objective, showing that the Germans had no intention of going beyond the line actually gained, which included Mont Kemmel and the rest of the area upon which Blue Cross had been used.

Blue Cross shell were used in increasing numbers throughout 1918, but in spite of the valuable effects attributed to them in Ludendorff's instructions, they were, taking them all round, ineffective in the field. The irritant effects produced by them were but transitory, for it was unusual for a man to get more than a slight dose before he adjusted the improved respirator which gave complete protection, and very often the affected man recovered so soon that it was unnecessary for him to be evacuated from his unit as a casualty.

In some cases, undoubtedly, the effects were more severe, and the pain, discomfort, mental depression and feeling of weakness were enough to put the affected man definitely out of action for perhaps as long as an hour or two. These cases were, however, in the minority, and many of them could be returned to duty again from medical units in the army area owing to their speedy recovery, so that the proportion evacuated to the base was not large. There was a general agreement in the reports received from the corps chemical advisers that Blue Cross shell were not much more effective than ordinary H.E. shell, and that the chlorarsines had little casualty-producing power, though at times men, especially working parties and troops during an advance, suffered considerable temporary inconvenience and distress from the fumes, while the necessity of wearing the box respirator hampered them in their work and increased their fatigue. The chemical adviser to the Vth Corps summarized the effects of Blue Cross in the following words : " It is a negligible menace so far as causing serious and prolonged casualties ; but it is a very real factor in a battle, particularly in a retreat, where both its moral and physical effects may greatly influence the issue during a limited number of hours." He further expressed the opinion that anything beyond a very mild dose led to a general decrease in the stamina and power of resistance, and thus contributed to the number of prisoners taken by the enemy.

In July 1918 the ammunition in the captured battery positions and divisional dump of a German division in the Moreuil sector, a normally active front, comprised 50 per cent. of H.E. shell, 19 per cent. of Blue Cross, 24 per cent. of Green Cross, and 7 per cent. of Yellow Cross. In September 1918 the proportions of the different varieties of shell in the German ammunition dumps opposite the British Third Army front were 60 per cent. H.E. and shrapnel, 30 per cent. Blue Cross, and 10 per cent. other gas shell; and opposite the Second Army front, 70 per cent. H.E. and shrapnel, 27 per cent. Blue Cross, and 3 per cent. other gas shell. The Germans were therefore apparently placing increased confidence in Blue Cross shell, though it is possible that they were influenced more by the H.E. value of these shell than by the hope of getting any great effect from the gas, for they never attributed casualty-producing power to the chlorarsines but put their reliance on their immediate irritant action. The hope of getting an increased destructive effect and a better dispersion of the gas cloud, and of making it more difficult to recognize the commencement of a gas bombardment, led the Germans in the later period of the war to increase the bursting charge in gas shell other than Blue Cross. H.E. Yellow Cross shell were introduced in their offensive of March 1918, and were used in increasing numbers during the succeeding months, but H.E. Green Cross shell only began to appear right at the end of the war.

A very good index of the actual proportion of the gas casualties attributable to the three different types of gas shell in 1918 is given by the following records of two medical units, the Vth Corps Gas Centre and No. 7 Stationary Hospital, Boulogne, in both of which the greatest care was taken to make a correct diagnosis from the nature of the symptoms and from the history of the cases.

The Vth Corps Gas Centre had the advantage of close co-operation with the corps chemical adviser, and was therefore able to obtain accurate information from the military side as to the nature of the gas shelling. Between 25th May and 9th October, 1918, this unit admitted 3,510 gas casualties, and the analysis given in Table X may be taken to represent the conditions in the southern half of the British front.

TABLE X.

Admissions to Vth Corps Gas Centre, 25th May to 9th October, 1918.

	Number.	Percentage.
Yellow Cross	2,926	83·4
Blue Cross	338	9·6
Green Cross	246	7·0
Total Admissions ..	3,510	

Between 25th May and 30th June the proportion of Blue Cross casualties admitted to this unit mounted to 17·3 per cent., and corresponded with an increase in the Blue Cross shelling.

No. 7 Stationary Hospital only dealt, of course, with cases evacuated from the casualty clearing stations to the base, and derived the majority of the casualties that it admitted from the northern half of the British front. An analysis of the gas cases admitted to this unit in the four months May to August 1918 is given in Table XI.

TABLE XI.

Admissions for Gas Poisoning to No. 7 Stationary Hospital, May–August, 1918.

	Number.	Percentage.
Yellow Cross	692	77·4
Blue Cross	85	9·5
Green Cross :—		
"Phosgene"	51	5·7
Lachrymators..	38	4·3
Not defined	28	3·1
Total Admissions ..	894	

The figures derived from these two sources are in close agreement. It will be seen that the proportion of casualties attributed to the action of the acute lung irritants is extremely low, and it is clear that during the mustard gas period Green Cross shell were nearly as ineffective as casualty-producers as in the period July 1916 to July 1917, nor do they appear to have given rise to a greater proportion of fatal cases. Green Cross casualties were actually somewhat more numerous during the mustard gas period than in the preceding twelve months, and it appears probable that this corresponded with an increasing tendency of the Germans to employ concentrated surprise bombardments rather than scattered shelling.

During the last two or three months of the war the increased proportion of Blue Cross shell used by the Germans led to an increase, though not a marked one, in the number of Blue Cross casualties. Notwithstanding the relative diminution in the number of Yellow Cross shell employed, mustard gas casualties remained high, for with the commencement of the British offensive in August the enemy's gas shell tactics changed. Yellow Cross shell were used much farther forward than previously, and bombardments of the front line system, forward posts, and possible assembly positions were frequent. On more than one occasion the enemy attempted to create an impassable zone in front of the forward positions by means of mustard gas, and it was noticeable that supplies of Yellow Cross shell were switched to those portions of the front where the Germans were most in fear of an attack, a fact suggestive that the demands for this type of shell were outrunning the supply. The precautions and general organization against gas, such as the provision of gas-proof dugouts, were necessarily less perfect in open than in trench warfare, and this was partly responsible for keeping up the number of casualties.

The figures shown in Tables XII and XIII are derived from the weekly returns of the D.G.M.S. for the whole of the mustard gas period and show the total number of casualties due to all kinds of gas shell admitted to casualty clearing stations and the deaths from gas poisoning in these units and in field ambulances, as well as the total number of mustard gas casualties admitted to hospitals on the lines of communication and the deaths from mustard gas poisoning in these units.

TABLE XII.

Gas Shell Casualties admitted to Casualty Clearing Stations and Deaths from Gas Shell Poisoning in Field Ambulances and Casualty Clearing Stations from the introduction of Yellow Cross Shell (Mustard Gas) on 12th–13th July, 1917.

Week ending.	Total Casualties.	Deaths.	Actions.
1917.			
21st July ..	2,934	101	
28th ,, ..	6,476	146	
4th Aug. ..	4,866	35	British offensive at Ypres, 31.7.17.
11th ,, ..	1,583	27	
18th ,, ..	1,890	36	
25th ,, ..	1,263	22	
1st Sept. ..	431	2	
8th ,, ..	1,614	17	
15th ,, ..	2,037	62	

TABLE XII—*cont.*

Week ending.	Total Casualties.	Deaths.	Actions.
1917.			
22nd ,,	894	24	
29th ,,	1,612	31	
6th Oct.	1,756	54	
13th ,,	512	12	
20th ,,	3,249	54	
27th ,,	1,933	26	
3rd Nov.	3,845	45	
10th ,,	2,675	49	
17th ,,	1,653	31	
24th ,,	1,106	26	Cambrai advance, 20.11.17.
1st Dec.	1,763	14	Bourlon Wood shelled, 30.11.17.
8th ,,	1,479	30	
15th ,,	768	9	
22nd ,,	288	4	
29th ,,	579	9	
1918.			
5th Jan.	653	9	
12th ,,	189	1	
19th ,,	198	5	
26th ,,	356	2	
2nd Feb.	903	7	
9th ,,	411	6	
16th ,,	408	3	
23rd ,,	660	16	
2nd Mar.	428	3	
9th ,,	904	28	
16th ,,	6,195	39	Cambrai salient shelled, 11–14.3.18.
23rd ,,	6,874*	36	Great German offensive, 21.3.18.
30th ,,	2,686*	30	
6th Apr.	1,302	10	
13th ,,	6,940	20	German offensive, Lys front, 9.4.18.
20th ,,	3,926	13	Villers Bretonneux shelled, 17.4.18.
27th ,,	4,544	30	Kemmel taken by Germans,25.4.18.
4th May	2,461	31	
11th ,,	1,721	14	
18th ,,	4,421	40	Fonquevillers shelled, 11–12.5.18.
25th ,,	3,918	32	German offensive on Aisne, 27.5.18.
1st June	3,495	48	
8th ,,	1,485	23	
15th ,,	1,135	24	
22nd ,,	525	22	
29th ,,	707	44	
6th July	781	11	
13th ,,	478	9	French offensive, Aisne–Château Thierry, 17.7.18.
20th ,,	605	5	
27th ,,	1,968	19	Villers Bretonneux shelled, 22.7.18.
3rd Aug.	2,286	23	
10th ,,	1,762	20	British offensive on Somme, 8.8.18.
17th ,,	3,720	23	
24th ,,	5,367	25	British offensive Scarpe-Somme, 21.8.18.

* Records incomplete.

TABLE XII—*cont.*

Week ending.	Total Casualties.	Deaths.	Actions.
1918.			
31st Aug. ..	6,265	54	
7th Sept. ..	6,134	36	Advance through Lens, 3–4.9.18.
14th ,, ..	2,590	36	
21st ,, ..	4,172	32	
28th ,, ..	2,578	12	Cambrai offensive, 27.9.18. Ypres advance, 28.9.18.
5th Oct. ..	4,315	24	
12th ,, ..	2,206	25	Cambrai – St. Quentin attack, 8.10.18.
19th ,, ..	4,407	31	
26th ,, ..	2,568	27	Scheldt–Le Cateau attack, 23.10.18.
2nd Nov. ..	2,162	23	Valenciennes attack, 1.11.18.
9th ,, ..	1,561	12	
16th ,, ..	367	9	
23rd ,, ..	27	1	
Total	160,970	1,859	

TABLE XIII.

Mustard Gas Casualties admitted to Hospitals on L. of C. and Deaths among these Casualties since the introduction of Mustard Gas.

Week ending.	Total Casualties.	Deaths.
July 1917	10,911*	188
7th Aug.	2,887	67
14th ,, ...	1,664	16
21st ,, ...	1,913	9
28th ,, ...	848	2
4th Sept.	312	1
11th ,, ...	1,413	3
18th ,, ...	1,760	15
25th ,, ...	876	5
2nd Oct.	1,389	13
9th ,, ...	1,507	16
16th ,, ...	1,124	18
23rd ,, ...	2,653	40
30th ,, ...	1,328	19
6th Nov.	3,003	28
13th ,, ...	1,614	16
20th ,, ...	1,187	8
27th ,, ...	744	14
4th Dec.	1,550	35
11th ,, ...	804	92
18th ,, ...	414	15
25th ,, ...	278	6

* Total gas poisoning admissions for the month; the majority due to mustard gas.

Table XIII—*cont.*

Week ending.	Total Casualties.	Deaths.
1918.		
1st Jan.	387	2
8th ,,	441	1
15th ,,	176	–
22nd ,,	146	–
29th ,,	189	–
5th Feb.	536	1
12th ,,	234	1
19th ,,	307	1
26th ,,	486	–
5th Mar.	306	1
12th ,,	601	1
19th ,,	4,783	17
26th ,,	4,401	40
2nd Apr.	2,031	18
9th ,,	1,851	5
16th ,,	5,456	56
23rd ,,	3,498	55
30th ,,	4,414	96
7th May	2,127	45
14th ,,	2,389	59
21st ,,	2,621	219
28th ,,	3,103	131
4th June	2,393	51
11th ,,	1,503	24
18th ,,	849	16
25th ,,	559	18
2nd July	519	29
9th ,,	480	30
16th ,,	276	8
23rd ,,	262	2
24th–27th July*	798	21
3rd Aug.	1,835	28
10th ,,	1,668	19
17th ,,	2,384	29
24th ,,	3,588	75
31st ,,	5,243	50
7th Sept.	3,751	41
14th ,,	2,914	71
21st ,,	3,114	60
28th ,,	1,858	47
5th Oct.	2,409	41
12th ,,	1,170	35
19th ,,	2,002	25
26th ,,	1,666	72
2nd Nov.	1,157	53
9th ,,	1,060	43
16th ,,	403	28
23rd ,,	117	12
30th ,,	32	5
7th Dec.	30	–
Total	124,702	2,308

* To bring date of L. of C. returns into correspondence with those of army areas.

As in Table VII, these figures underestimate the total number of casualties caused by gas shell, for there is no mention of deaths previous to admission to medical units, nor of deaths on the lines of communication from other gases than mustard gas, neither are the numbers given of mild gas casualties returned direct to their units from field ambulances, nor, what is perhaps of greater importance, those of gas casualties taken prisoner by the enemy. These omissions are not, however, so serious as would appear at first sight. No fatal case of Blue Cross poisoning is known to have occurred, while the nature of the symptoms caused by mustard gas was such as to render it necessary to treat even the mildest cases in a medical unit for at least a few days, and the delay in the onset of serious symptoms ensured that no deaths from mustard gas poisoning occurred before admission to medical units. The general character of the casualties caused by Green Cross and the mortality amongst them appears to have been much the same as in the previous twelve months, and from what has been said previously one would judge that the great bulk of both the casualties and deaths due to acute lung irritant gases must be included in the tables.

Comparison of Table XIII with Table XII shows that 124,702, or 77·5 per cent., of the 160,970 total gas casualties admitted to the casualty clearing stations reappear in the records of hospitals on the lines of communication with the definite diagnosis of mustard gas poisoning. For a reason that will be stated below the figures given for the mustard gas casualties at the base are probably too low, and taking into account the data from individual medical units given in Tables X and XI, it may be assumed that in round figures 80 per cent. of the total gas shell casualties during the mustard gas period were due to Yellow Cross shell, 10 per cent. to Blue Cross, and 10 per cent. to Green Cross. The great casualty-producing power of mustard gas in comparison with the other warfare gases is obvious, and this contrast is rendered still clearer in Chart I, which shows graphically the weekly admissions of gas casualties from 15th July, 1916, the date of the commencement of "lethal" gas shelling, till the end of the war, as well as the casualties suffered in the different cloud gas attacks. The great fluctuations in the casualties during the mustard gas period were determined mainly by variations in the extent of the gas shelling.

Owing to the long period which may elapse between the date of exposure to mustard gas and the date of death, and the

CHART SHOWING BRITISH CASUALTIES FROM GAS ATTACKS 1915—1918.

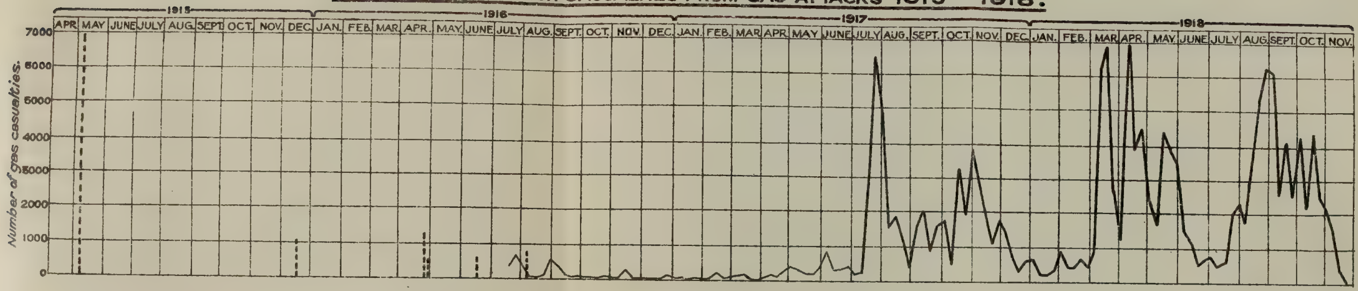

Chart I - BRITISH GAS CASUALTIES - 1915 to 1918.

The vertical spaced lines indicate the gas casualties caused by cloud gas attacks. Exact data are lacking regarding the attacks that took place between April 22nd and May 24th, 1915, and the chart only represents the approximate total number of gas casualties that were admitted to medical units during this series of gas attacks. The remaining cloud gas attacks resulted in a total of 4,207 gas casualties with an average mortality of 24.0 per cent. The thin continuous line indicates the number of gas shell casualties caused each week during the "lethal" gas shell period, July 15th, 1916 - July 12th, 1917. The total gas shell casualties during this period amounted to 8,806 with an average mortality of 6.0 per cent.

The thick continuous line indicates the number of gas shell casualties caused each week during the mustard gas period, July 13th, 1917 to the end of the war. The total gas shell casualties during this period amounted to 160,970 with an average mortality of 2.6 per cent.

During the period May 1915 to July 1916 a small number of gas casualties resulted from bombardments with lacrymator gas shell. These are not represented in the chart as data regarding the numbers are lacking. None of these casualties died.

1915.	April 22 - May 24.	Six cloud gas attacks, Ypres sector.
	Dec. 19	Cloud gas attack, Wieltje sector.
1916.	April 27 and 29.	Cloud gas attacks, Hulluch sector.
	April 30.	Cloud gas attack, Wulverghem sector.
	June 17.	Cloud gas attack, Wulverghem sector.
	July 1.	Battle of the Somme.
	July 14 - 15.	Lethal gas shell first used.
	Aug. 8.	Cloud gas attack, Wieltje sector.
1917.	April 9.	Battle of Arras.
	June 6.	Battle of Messines.
	July 12 - 13.	Mustard gas shell first used.
	July 31.	British offensive at Ypres.
	Nov. 20.	Cambrai advance.
	Nov. 30.	Bourlon Wood shelled.
1918.	March 11 to 14.	Cambrai salient shelled.
	March 21.	Great German offensive.
	April 9.	German offensive. Lys front.
	April 17.	Villers Brettonneux shelled.
	April 25.	Kemmel taken by Germans.
	May 11 - 12.	Fonquevillers shelled.
	May 27.	German offensive on Aisne.
	July 17.	French offensive Aisne - Chateau Thierry.
	July 22.	Villers Brettonneux shelled.
1918.	Aug. 8.	British offensive on Somme.
	Aug. 21.	British offensive, Scarpe - Somme.
	Aug. 18 to 30.	German withdrawal from Lys salient.
	Aug. 31.	British capture Peronne.
	Sept. 3 - 4.	British advance through Lens.
	Sept. 27.	Cambrai offensive.
	Sept. 28.	Ypres advance.
	Oct. 8.	Cambrai - St. Quentin attack.
	Oct. 23.	Scheldt - Le Cateau attack.
	Nov. 1.	Valenciennes attack.
	Nov. 4.	General British attack.

605. 8/8/39 4940/1322.

Malby&Sons, Lith.

consequent lack of correspondence between the casualties and deaths reported on any given date in the returns, exact calculation of the case mortality for any given period presents considerable difficulties, though it is possible to give a reasonable approximation. These data are given in Table XIV.

TABLE XIV.

Mortality amongst Gas Shell Casualties in France during the Mustard Gas Period, July 1917 *to the end of the War.*

Period.	Casualties.	Deaths.	Deaths per 100 Casualties.
July and August 1917	19,012	649	3·4
September and October 1917 . .	14,038	412	2·9
November and December 1917 . .	14,156	434	3·1
30.12.17—12. 1.18	842	10	1·2
13. 1.18—26. 1.18	554	8	1·5
27. 1.18— 9. 2.18	1,314	15	1·1
10. 2.18—23. 2.18	1,068	19	1·8
24. 2.18— 9. 3.18	1,332	37	2·8
10. 3.18—23. 3.18	13,069	149	1·1
24. 3.18— 6. 4.18	3,988	57	1·4
7. 4.18—20. 4.18	10,866	207	1·9
21. 4.18— 4. 5.18	7,005	154	2·2
5. 5.18—18. 5.18	6,142	373	6·1
19. 5.18— 1. 6.18	7,413	216	2·9
2. 6.18—15. 6.18	2,620	75	2·9
16. 6.18—29. 6.18	1,232	127	10·3
30. 6.18—13. 7.18	1,259	33	2·6
14. 7.18—27. 7.18	2,573	75	2·9
28. 7.18—10. 8.18	4,048	93	2·3
11. 8.18—24. 8.18	9,087	178	2·0
25. 8.18— 7. 9.18	12,399	220	1·8
8. 9.18—21. 9.18	6,762	166	2·5
22. 9.18— 5.10.18	6,893	110	1·6
6.10.18—19.10.18	6,613	163	2·5
20.10.18— 2.11.18	4,730	139	2·9
3.11.18— 7.12.18	1,955	46	2·4
Unrecorded	—	2	—
Total	160,970	4,167	2·6

The figures for periods in 1917 are based on weekly returns without correction for dates on which fatal cases were gassed.

The remaining periods are based on weekly returns, but with deaths on lines of communication correctly distributed to the periods in which the cases were actually gassed.

In order to arrive at the figures shown in this table the following procedure has been adopted. The returns of the D.G.M.S. do not show the date on which fatal cases were gassed during the period 13th July to 30th December 1917, and the mortality is therefore only given for successive periods of two months during this time, the figures for casualties and deaths being taken directly from Tables XII and XIII without any further correction. The length of these periods and the large number of casualties involved will largely compensate for the error just mentioned. From 30th December 1917 onwards the dates on which the cases that died on the lines of communication were originally gassed are given in the returns, and the mortality figures have been obtained for successive periods of fourteen days as follows. Total casualties for the period in question are taken from Table XII ; total deaths are made up of deaths given in Table XII for the same period without any correction, and the true number of deaths that occurred on the lines of communication amongst casualties gassed during this period. It will be seen that the correction of the death-rate is in this case only partial, but it should be noted that during the whole of 1918, 1,680 deaths (and these are the ones that have been corrected) occurred on the lines of communication, as opposed to 993 reported in army areas, while from the end of March 1918, onwards, twice as many deaths occurred on the lines of communication as in army areas ; moreover, the deaths in army areas include those due to poisoning with Green Cross substances, which occur very soon after exposure, and therefore correspond more closely in respect to date with the number of admissions given in the tables. The short periods of fourteen days have been deliberately chosen with a view to giving some idea of the variation of mortality throughout the year.

From 15th September, 1918, onwards, the weekly returns of the D.G.M.S. show the dates on which all fatal cases, both in army areas and on the lines of communication, were gassed, and the true weekly mortality can therefore be given for the last nine weeks of the war. These figures are given in Table XV, but comparison with Table XIV will show that full correction makes little difference to the results.

TABLE XV.

Corrected Mortality amongst Gas Shell Casualties during Period 15th September, 1918, to the end of the War.

Fatal Cases occurring both in Army Areas and on the Lines of Communication correctly distributed to the Periods in which they were actually Gassed.

Period.	Casualties.	Deaths.	Deaths per 100 Casualties.
15. 9.18—21. 9.18	4,172	95*	2·3
22. 9.18—28. 9.18	2,578	24	0·9
29. 9.18— 5.10.18	4,315	80	1·9
6.10.18—12.10.18	2,206	62*	2·8
13.10.18—19.10.18	4,407	106	2·4
20.10.18—26.10.18	2,568	66†	2·6
27.10.18— 2.11.18	2,162	69	3·2
3.11.18— 9.11.18	1,561	34	2·2
10.11.18— 7.12.18	394	4†	1·0
Total	24,363	540	2·2

* Exclusive of one death on L. of C., date of gassing unrecorded.

† Exclusive of one death at C.C.S., date of gassing unrecorded.

Table XVA shows the figures from 22nd September, 1918, onwards, in fortnightly periods for comparison with figures in Table XIV.

TABLE XVA.

Period.	Casualties.	Deaths.	Deaths per 100 Casualties.
22. 9.18— 5.10.18	6,893	104	1·5
6.10.18—19.10.18	6,613	168	2·5
20.10.18— 2.11.18	4,730	135	2·9
3.11.18— 7.12.18	1,955	38	1·9

Note :—Fifteen fatal cases which occurred in field ambulances are assumed in these tables to have been gassed during the week in which their deaths were reported, the actual dates when they were gassed being unrecorded.

Unfortunately, another source of error appeared in the weekly returns in these last few weeks of the war. An attempt was made to render the returns of greater value by arranging for a more complete differentiation of the cases according to the symptoms caused by the different classes of warfare gas, but it was soon apparent that in many medical units only those cases were being returned as " mustard gas cases " in which the field medical card bore these words as the original diagnosis, and that if the word " mustard " did not figure in this place the cases were often returned as casualties due to other gases in spite of the clear nature of the symptoms. It was fairly certain that there had been a slight error of this nature throughout the whole of the mustard gas period, but it became very prominent after 15th September 1918, and for this reason the returns from the lines of communication after that date cannot be regarded as a true index of the real proportion of mustard gas cases, but are an under-estimate, though Blue Cross casualties were undoubtedly on the increase at the time. This error even affected the returns of deaths from mustard gas poisoning on the lines of communication after 15th September, thus, while the returns from the lines of communication showed that 421 deaths from gas shell poisoning occurred during the period 15th September to 7th December, only 308 of these were specifically attributed to mustard gas. An investigation made at the time in the Etaples-Camiers area showed, however, that during the period 20th October to 9th November, 23 deaths had been returned as due to gases other than mustard gas, though on examining the field medical cards of these cases mustard gas could clearly be identified as the cause of death in 22 of them, and in only one case was the diagnosis doubtful owing to insufficient information. It has seemed advisable, therefore, in Tables XIII, XIV, XV, and XVA, to ascribe the whole of the deaths from gas poisoning that occurred on the lines of communication during this period to mustard gas, since it is certain that only a trifling number of fatal cases of acute lung irritant poisoning can have occurred farther back than the casualty clearing stations.

Taking the figures as a whole, the mortality amongst the gas casualties in France during the mustard gas period was strikingly low. Acute lung irritants were the only warfare gases besides mustard gas to cause death, and assuming, as appears reasonable, that the mortality amongst cases affected by the acute lung irritants was the same as in the " lethal " gas shell period, and making allowance for the Blue Cross casualties, amongst whom there was no mortality, the figures for the death-rate will practically hold good as they stand for mustard gas casualties alone.

Table XIV shows that though there was no definite variation in the death-rate amongst gas casualties in the first six months of the mustard gas period, such variation did undoubtedly occur in 1918. As has been pointed out, the heavy Yellow Cross bombardments in March 1918 were characterized by an unusually mild type of casualty. During April the mortality increased slowly, and during May, June, and July it reached a figure but slightly below the average shown in July to December 1917. There was a distinct fall in the mortality during August and September, but in October and November the death-rate was almost as high as in May to July. The proportion of severe cases of mustard gas poisoning and the incidence of blistering varied in a manner similar to the mortality, blistering being rare in March, relatively common in the summer, and then becoming less frequent during the last two months of the war.

It seems quite probable that alterations of air and ground temperatures played some part in this variation in the severity of the cases. In March the average temperature reached 46° to 48° F. in the middle of the day, while the temperature during the night varied from 35° to 38° F.; in July and August the corresponding temperatures were about 68° F. and 52° to 58° F. The higher the temperature the more would evaporation of mustard gas from the ground be favoured, with a consequent increase in the chance of severe lesions of the eyes and lungs, while sweating and the tendency to discard clothing during muscular work in the hot weather would favour the action of mustard gas on the skin. The factors which have been already mentioned as helping to keep up the number of the casualties—the change from trench warfare to open warfare, and the alteration in the German gas shell tactics when the British offensive began—very likely contributed to the increased death-rate in the summer and autumn, and the more frequent use of H.E. Yellow Cross shell may perhaps have led to a severer type of casualty. The inexperience of new drafts sent to replace casualties is yet another factor. The influenza epidemic of May and June 1918 did not seem to render mustard gas casualties much more susceptible to pulmonary trouble, but it is possible that the much more severe epidemic of October and November may have been a contributory factor to the increased mortality amongst the gas casualties in those months.

It will be seen that two of the periods shown in Table XIV, namely 5th to 18th May, 1918, and 16th to 29th June, 1918, are marked by an exceptionally high mortality. Comparison with Tables XII and XIII makes it clear that the deaths in the first of these two periods were mainly caused by mustard gas, and that the larger proportion of the deaths occurred amongst the casualties evacuated to the base. Between 5th and 18th May, 1918, there were only two outstanding bombardments with Yellow Cross shell, namely, in the Second Army area at Le Tir Anglais on the night of 10th–11th May, and in the Third Army area at Fonquevillers on the night of 11th–12th May. It was the second of these bombardments which was responsible for the heavy mortality. The returns from the lines of communication areas afforded the information shown in Table XVI.

TABLE XVI.

L. of C. Area.	Deaths among Casualties gassed on		
	10.5.18.	11.5.18.	12.5.18.
Boulogne, Etaples, Calais ..	2	13	1
Rouen,* Le Tréport, Amiens, Abbeville.	10	112	69

* For the week ending 21st May, 1,326 mustard gas cases were admitted, and 179 deaths occurred from mustard gas poisoning at Rouen. Of the fatal cases, 84 were gassed on 11th May and 22 on 12th May.

Boulogne, Etaples and Calais received cases almost entirely from the First and Second Armies, the other group of bases receiving cases from the Third and Fourth Armies. The Fourth Army returned only a small number of gas casualties during the period in question, and one can therefore attribute to the shelling of Fonquevillers most of the deaths reported from Rouen, Le Trêport, Amiens, and Abbeville among men gassed on 11th and 12th May. Rather more than 2,000 of the 2,473 gas casualties returned by the Third Army for the period 5th to 18th May, as well as 16 of the deaths that occurred in the army area, were also derived from the corps affected by the shelling of Fonquevillers, and the actual mortality amongst the casualties caused by this bombardment cannot therefore have been much below 9 per cent. A court of enquiry found that there was a lack of anti-gas discipline on this occasion. Troops were very casual about wearing their respirators, men sleeping in cellars were not roused sufficiently quickly, and billets in the village were not evacuated soon enough.

In the period 16th to 29th June, 1918, when the total number of casualties involved was much smaller, the excessive death-rate was traced to the heavy Yellow Cross shelling of three siege batteries during the night of 24th–25th June. The casualties that were caused in these batteries are shown in Table XVII.

TABLE XVII.

Gas Casualties in three Siege Batteries, 24th to 25th June, 1918.

Battery.	Gas Casualties.	Deaths.			Deaths per 100 Casualties.
		Army Area	L. of C.	Total.	
A ..	86	20	24	44	51·1
B ..	24	10	4	14	58·3
C ..	23	—	1	1	4·3

This large number of exceptionally severe casualties was again the result of bad anti-gas discipline. Respirators were not worn after the bombardment, though the ground was heavily contaminated. In the case of battery marked A in the table, the officer on duty became a casualty early in the bombardment, and no one took charge of the situation effectively till too late. In the case of battery marked C, practically the whole of the casualties occurred in a party that stayed behind pulling out a gun, while the remainder of the unit evacuated the position.

Stress has intentionally been laid on these two episodes, for they make it quite evident that the low average mortality during the mustard gas period must be largely attributable to the general high level of anti-gas organization and discipline. Mustard gas is an intensely toxic substance, and any gross failure in protective measures at once showed up its deadly nature. There were, of course, occasions when a very high death-rate occurred amongst a limited number of mustard gas casualties, just as amongst casualties caused by other gas shell, owing to unavoidable mischance. The First Army, for instance, returned 96 gas casualties, with 14 deaths, for the week ending 22nd June, 1918, but in this case 15 men were buried in a dugout by a Yellow Cross shell which burst at the entrance, and 12 of them died.

Projector Attacks, December 1917 *to May* 1918.

Projector gas attacks made by the Germans on the British front were few in number, and for the most part on a small scale. The casualties and deaths that resulted from these are included in Tables XII, XIII, and XIV, and the details derived from the reports of chemical advisers to armies are shown in Table XVIII :—

TABLE XVIII.

Casualties resulting from German Projector Gas Attacks.

Date.	Place.	Total Gas Casualties.	Deaths.
11.12.17	Cambrin Givenchy	78	21
31.12.17	N.W. Lens	34	2
26. 1.18	Lens	2	—
31. 1.18	Lens	19	3
14. 2.18	S.E. Bullecourt.	66	4
16. 2.18	Lens	10	—
19. 2.18	Lens	9	—
6. 3.18	Avion	70	13
7. 3.18	N.W. Gonnelieu	40	6
7. 3.18	,, ,,	17	7
21. 3.18	Monchy	—	—
14. 4.18	Lens	—	—
22. 4.18	Lens	—	—
1. 5.18	Hill 70	7	—
19. 5.18	St. Elie*	75	20
31. 5.18	Hill 70	17	5
	Total	444	81 = 18·2 per 100 casualties.

* Captured British projectors.

It will be seen that though the actual number of casualties caused by any one attack is not great, the average death-rate approaches the figure found in the cloud gas attacks. The British troops had so much experience of their own projector method of discharging gas that when the Germans imitated this method they were quick to recognize the discharge, and in many of the cases had adjusted their respirators before the bombs fell. On more than one occasion good anti-gas discipline prevented the occurrence of any casualties. The few German projector attacks made on parts of the front held by the French or American troops gave results similar to those indicated in Table XVIII.

Use of Warfare Gas by the British.

The development of a method for retaliating on the enemy with warfare gas was taken up soon after the original German cloud gas attacks in the spring of 1915. Four special companies of Royal Engineers were trained in the liberation of gas from cylinders, and cloud gas attacks with chlorine (the only gas that could be supplied in sufficient quantity in time) were made at the battle of Loos on 25th and 27th September, 1915. The wind was not very favourable for the attempt, but, notwithstanding this, the effect on the Germans was considerable. Further cloud gas attacks were made on 13th October on about the same front. The British suffered 2,911 casualties amongst their own troops during these gas attacks. Of these, 550 were attributed to the enemy's lachrymator shell, and this number seems likely to have been an underestimate, the remainder being attributed to British gas. It is not surprising that the troops should have suffered casualties from this cause. The method of warfare was novel, the special troops operating the cylinders had had but little time for training, the design of the valves and fittings of the cylinders was not yet perfect, and allowed a certain amount of leakage of gas, hostile shelling was heavy, and in some instances cylinders were burst by shell fire, whilst the infantry passed to the assault very soon after the gas discharge ended, and before the wind had entirely dispersed the gas from trenches and hollows in the ground. Only ten men appear to have been actually killed by the gas, as a result of burst cylinders or from some accidental cause. Fifty-five of the gas casualties were classed as severely gassed in the reports from medical units. All the remaining cases were evidently of the mildest description, and needed little or nothing in the way of treatment. Most of the troops had had no experience of gas other than lachrymator gas shell, and the alarming stories which were circulated in the early days of gas warfare had given rise to exaggerated ideas as to the potency of warfare gas and undermined men's confidence.

There is little doubt, in fact, from the reports of medical units, that the majority of casualties resulting from British gas about the time of the battle of Loos were really more frightened than hurt. A report from the West Riding casualty clearing station, which admitted 248 gas casualties, stated: "The majority of cases of gas poisoning received at this hospital showed no sign of that condition," while other medical officers frankly admitted that they were so handicapped by their lack of experience of cases of gas poisoning that they were often in doubt whether they were dealing with men suffering from gas poisoning or not.

A few further cloud attacks were made in the winter of 1915 and the early part of 1916, and meanwhile, the original four special companies were expanded into a brigade of twenty-one companies. The design of the apparatus for a cylinder discharge was greatly improved, and the 4 in. Stokes mortar was taken into use for firing both gas and smoke bombs. From 24th June, 1916, until the winter, numerous cloud attacks, many of which were on an extensive scale, were made not only on the Somme battle front, but also on many other parts of the British front, while frequent use was made of the Stokes mortars for creating smoke barrages during active operations. The gas mainly used in the cylinders was a mixture of chlorine and phosgene, for large supplies of the latter had by this time become available.

In September 1916 projectors of rough design were used for the first time opposite Thiepval and Beaumont Hamel, and the results obtained were so promising that large numbers of improved design were manufactured during the winter of 1916–1917, and the special companies were trained in the use of this new weapon. The first projector operation on a large scale took place on 4th April, 1917, at the commencement of the battle of Arras, and after this date a great number of projector discharges and hurricane gas bombardments by 4 in. Stokes mortars, as well as numerous cloud gas attacks, were made on all parts of the front. On a few occasions incendiary oil drums were fired in projector discharges, and both smoke and thermite bombs were frequently used with Stokes mortars. By the end of the war the special brigade had carried out 768 separate gas operations with the liberation of 5,700 tons of gas.

A small number of lachrymator artillery shell filled with ethyl-iodoacetate was used during the first battle of the Somme, but it was not till the beginning of the battle of Arras in 1917 that the supply of artillery gas shell, filled either with lachrymator or lung irritant substances, or with hydrocyanic acid, became ample, and after that date artillery gas shell were extensively employed. Mustard gas was first used by the French in artillery gas shell in June 1918, and by the British at the end of September.

It is unnecessary to deal at length with the effects of the British cloud gas attacks, for the statements of prisoners and the evidence of captured documents make it clear that the results were of the same general character as those obtained in the German cloud gas attacks, which have already been dealt with in detail. The repeated issue of warnings and instructions showed how greatly the Germans feared the British gas attacks, but their dread of projector gas attacks was even greater than of cloud gas attacks. The following translation of a German divisional report regarding a British projector discharge on Ablainzeville on 18th June, 1918, gives an excellent illustration of this mode of gas warfare, and shows how formidable the weapon proved even when warning of the probability of an attack had been issued to troops in the threatened sector.

"5th Bav. Res. Div. Div. Battle H.Q.
"No. 7671/1a/G.O. 20.6.18
"To XVIII Corps.

"At 1.50 a.m. on 18th June, 1918, the enemy's artillery, which had been moderately active all night, suddenly opened a heavy burst of fire from guns of small and medium calibre on Ablainzeville and the adjoining trench system. Heavy machine gun fire was heard two or three minutes later, while the artillery bombardment remained undiminished, and the enemy's gas projectiles fell shortly after this. At the time the wind was north-west with a velocity of about 9 miles per hour.

"The flash of the discharge when the projectors were fired was only seen by a part of the garrison of Ablainzeville, and by a trench mortar working party which was at work in the sunken road between Ablainzeville and Ayette. The flash, and the concussion which followed it, were taken for the explosion of an enemy ammunition dump and were not regarded as anything unusual, since explosions of dumps have been frequent of late, in consequence of our harassing fire at night. A vice-serjeant-major of the trench mortar detachment appears to have been the only man to hear the whirring noise of the projectiles; others declare that this noise was completely drowned by the heavy artillery and machine gun fire.

"This ingenious concealment of the surprise gas bombardment by means of artillery and machine gun fire resulted in the majority of the garrison taking cover, and the first intimation of what they had to deal with was afforded by the burst of the gas projectiles.

"In spite of this the gas alarm was given and gas masks put on in time in most places. It was only in places where direct hits were obtained on the entrances of dugouts, or in their immediate neighbourhood, that the gas developed so rapidly and in such concentration as to prevent the occupants from getting their gas masks on soon enough or putting them on properly. The medium Minenwerfer emplacements in Ablainzeville also received two direct hits in the immediate vicinity of their detachments. Rapid escape from the thick gas cloud was only possible in places where there was a certain amount of cover against the artillery shell which were falling at the same time, and against splinters.

"The number of gas projectiles fired into Ablainzeville may be estimated at several hundred.* The points of impact of the projectiles are distributed over the greater part of the village, and are especially numerous in the middle of the village, where the dugouts for the supports are situated. The front line only received a few hits.

"The gas surprise bombardment, which principally affected the 12th Reserve Infantry Regiment, coincided with the relief of the 3rd Battalion by the 1st Battalion, and the majority of the 3rd Battalion were still in the trenches. In addition to these, some of the company of the 10th Reserve Infantry Regiment immediately to the north, and of the trench mortar detachment, were affected by the gas bombardment.

"The position of the British projectors has not yet been identified with certainty. On the morning of 16th June, 1918, the division carried out a destructive bombardment on the sunken road in map square 720, since the installation of a projector battery was suspected there from aeroplane photographs. Confirmation of this suspicion was not afforded by the shoot.

"The village of Ablainzeville offers a favourable target for gas surprise bombardments, since the ruins of the houses, as well as the numerous hedges and rows of bushes, hinder the dispersion of the gas cloud. The dugouts in the village were furnished with gas curtains to close the entrances, and where gas curtains were not available, with tent squares or British blankets. Gas alarm apparatus was provided in each company sector.

"As the division was aware, on the 13th and 14th June, of the presence of British gas projectors in front of the right flank of the 17th Infantry Division, the brigades and regiments received information about this in writing. The attention of the regimental gas officer was called, in a written memorandum by the divisional gas officer, to the necessity for renewed instructions regarding British gas projector bombardments. In addition to this, the divisional gas officer had discussed the question of the installation of British gas projectors personally with the commanders of the 12th Reserve and 10th Reserve Infantry Regiments, on the occasion of the relief on the 15th June. According to the commander of the 12th Reserve Infantry Regiment, the battalions were warned on the same day of the possibility of a British gas projector bombardment, and that a specially sharp look-out and more stringent 'gas alert' must on this account be maintained. The surprise bombardment did not therefore take the battalion unawares.

"Attention was also repeatedly drawn in the written orders of the division to the correct method of carrying the gas mask in the forward positions.

"The casualties that resulted from the gas projector bombardment were as follows :—

2 Officers	Killed (12th Reserve Infantry Regiment).
51 O.R.	Killed
66 O.R.	Gassed

"Of the two officers, one had been regimental gas officer for over a year, and had had four years' war service and was a particularly active and skilful officer. The fact that even this officer was not able to protect himself in time serves to indicate how difficult it is to recognize enemy gas projector bombardments soon enough.

"Only a few of the men who were gassed died at once. Many of the men felt perfectly well after the bombardment. The O.C. 3rd Battalion 12th Reserve Infantry Regiment states that immediately after the bombardment the companies reported that there were practically no gas casualties. Owing to the fact that symptoms did not appear till later on, many of the men marched back with their companies on relief, under the impression that they had got through the affair satisfactorily. Several hours elapsed before they reported sick. The fatal course of the delayed illness was particularly striking.

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* 975 drums were fired, filled with phosgene ; wind N.W., 4 m.p.h.

"The gas in question is doubtless the mixture of chloropicrin, phosgene, and chlorine, long recognized as exceptionally effective, a single breath of which may prove fatal if the concentration is great enough. Coughing was evident at the commencement, and burning and stinging in the chest was felt as well.

"The principal causes of the casualties were as follows :—

(1) The ingenious concealment of the firing of the projectors by means of a simultaneous burst of artillery and machine gun fire, which resulted in the discharge and the whirring noise of the projectiles being missed.

(2) The relief of the garrison of Ablainzeville, which led to two battalions of the 12th Reserve Infantry Regiment being surprised by gas simultaneously. In view of the relief, the men had rolled up some of the gas curtains in order to facilitate the traffic in the entrances to the dugouts.

(3) The numerous direct hits immediately in front of, and sometimes in, the entrances of dugouts."

Captured documents and the interrogation of prisoners gave evidence of the numerous casualties suffered by the Germans from projector discharges, though the number of casualties resulting from a single projector bombardment was, of course, far less than from a cloud gas attack, owing to the narrower sector affected and the smaller quantity of gas liberated. It is clear from the evidence that the British projector discharges were far more effective than the German, and this is not surprising when one takes into account the magnitude of the operations, the size of the British projector drum, which held twice as much liquid gas as the German, and the great absorbing power of the British respirator, as compared with the German. The Germans recognized that absolutely certain protection could not be guaranteed with their defensive measures in the case of direct hits during projector bombardments owing to the great concentration of the gas, and gave orders that dugouts should be vacated, in spite of heavy shelling, if a thick gas cloud gained entry. Yet in one of the German projector attacks five of the bombs burst in a British trench without harming the occupants, who had adjusted their respirators in time.

The British had another great advantage over the Germans in the prevailing direction of the wind, which allowed them to employ both cloud and projector attacks on an extensive scale. The wind favoured the Germans only in the spring of the year, and even then the direction was such that cloud attacks could only be made with safety in a few sectors. During the remainder of the year the wind was to the advantage of the British, and, as has been pointed out, they were able to make gas attacks at practically all parts of the front, a fact which naturally increased the chance of gaining a surprise effect.

The severity of the losses which the Germans suffered from the acute lung irritant gases used in the British cloud and projector attacks can be gauged to some extent from the official pamphlets which they issued on the diagnosis and treatment of gas poisoning. The first of these appears to have been issued about September 1916, after the British gas attacks during the battle of the Somme, and bears evidence that the problem of gas poisoning was still incompletely understood. The second edition, which was based on the information obtained up to the end of 1916, is a great improvement on the first. There was a third revised edition from the standpoint of June 1917, and some additional instructions were circulated from the standpoint of August 1917. The final edition, from the standpoint of January 1918, was followed by a supplement issued in May 1918. The first two of these editions confined themselves to the questions of carbon monoxide and acute lung irritant poisoning. No copy of the third edition has been obtained. The fourth edition gave in addition a brief account of hydrocyanic acid poisoning, and an extensive and accurate account of mustard gas poisoning, based in the main on accidental casualties caused by leaky shell, prematures, or the explosion of dumps of Yellow Cross ammunition, for at this time the allies had no supplies of mustard gas. As regards poisoning by the acute lung irritant gases, the accounts given in the later editions of the German pamphlets agree closely with that given in the second edition of the British pamphlet, and the following passages from the supplement of May 1918 are significant of the difficulties entailed in dealing with such casualties :—

" Definite cases of gas poisoning are harmed by any form of transport, since this leads to unavoidable muscular exertion. . . . On the other hand, the choice of the time for transport is often determined by military considerations, and the ultimate fate of the casualty depends on appropriate treatment, and, above all, on trained nursing, which is best afforded in the gas station of a permanent hospital. An attempt should therefore be made to transfer the case from the medical dugout to a gas station within an hour or two of being gassed. If the case is only taken as far as the main dressing station a decision has to be made whether further transport or the lack of efficient nursing constitutes the greater danger. . . . The value of a gas casualty station in an army field hospital rests on the fact that experienced medical officers, detailed organization of the hospital, and, in particular, a thoroughly trained male and female nursing staff alone render it possible to do justice to individual gas cases and to attain favourable results, especially when there is a great influx of cases."

The Germans, as well as the British, had to contend with the difficulty of correct diagnosis in the case of those who alleged or feigned gas poisoning, and were forced to lay down stringent rules regarding the treatment of malingerers.

After the battle of Loos only a few casualties among the British troops were attributable to their own gas in spite of the frequent presence of large quantities of gas in the trenches awaiting discharge, for precautions were always taken to warn all troops in the vicinity of the place from which the gas was to be discharged, and as many of the infantry as possible were withdrawn from points which appeared at all likely to be dangerous. On one occasion a sudden eddy back of gas during a cylinder discharge caused about 200 casualties among the infantry, of whom 19 died, and in addition to this 29 fatal cases of gas poisoning were recorded on other occasions owing to projector drums falling wide or from gas cylinders being burst in the trenches by hostile shell fire.

The value of the British artillery gas shell is well shown in the following words taken from a report by a German Army Commander during the battle of Arras, 1917: "The enemy made extensive use of gas ammunition. Our masks afforded complete protection; however, the fighting resistance of the men suffered considerably from wearing the respirator for many hours. Horses were greatly affected by the gas; in many cases the failure of the ammunition supply has to be attributed to this. From the same cause it seems that the timely withdrawal of batteries could not be effected. Artillery activity seems to have been paralysed by the effects of gas." The subsequent use of artillery gas shell for counter-battery work and for interfering with the movement of ration parties and reliefs proved very successful. The introduction of mustard gas shell by the French in June 1918 took the Germans by surprise, for they had not anticipated that the Allies would be able to manufacture this substance so soon. It spread consternation through their troops owing to the number and the type of the casualties that resulted, whilst their medical officers appear to have found themselves in difficulties in spite of the information given in the German pamphlet. The casualty-producing power of these French shell, as well as of the British mustard gas shell which began to come into use three months later, was just as great as that of the Yellow Cross shell, and depended on the insidious character of the poison, a point which was emphasized in detailed instructions for dealing with the new danger issued under Ludendorff's signature on 21st June, 1918.

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CHAPTER X.

PROTECTIVE MEASURES AGAINST WARFARE GAS.

THE incidence of gas casualties in the field was very closely dependent on the effectiveness of the measures devised and used for protection against warfare gases. It was of the greatest importance that every medical officer should understand thoroughly the use and true value of any protective appliance and the significance of the various defensive measures against gas, for he had perhaps a better chance than anyone else of identifying any real failure in these defensive measures, owing to his opportunities for questioning the casualties and studying their clinical symptoms. The nature of these symptoms might suggest the use by the enemy of some new poisonous substance capable perhaps of penetrating the respirator, or of so subtle a character as to defeat the measures previously found sufficient for protection. By questioning the casualties as to the reason why they were gassed, a medical officer might be convinced of the existence of flaws in the instructions regarding defence against gas that could be remedied. While his primary duty is the treatment of his cases, he should never forget the overwhelming importance of effective preventive measures in the case of gas warfare. In order, therefore, to appreciate fully the conditions under which gas casualties were caused during the war it is essential to consider in some detail the protective measures that were adopted, the more so as the Army Medical Department was for a long time responsible for the production of protective appliances. For convenience these protective measures may be grouped under the headings (*a*) general anti-gas organization; (*b*) individual protection; (*c*) collective protection.

General Anti-gas Organization.

On the commencement of gas warfare the organization of defence against gas fell within the province of the Adjutant-General's branch of the staff, and the onus of providing protective appliances and of formulating instructions for their use had to be borne by the medical services. Within a day or two of the first use of poisonous gas by the Germans a laboratory had been started on a small scale at General Headquarters, so that any material captured from the enemy might be examined without delay and suggestions regarding defensive appliances might be tested, while steps were at once taken by the Army Medical Department in England to organize the manufacture of respirators.

Defensive Organization in England.—Laboratories in the Royal Army Medical College at Millbank were equipped and staffed for research upon respirator design under Major P. S. Lelean, R.A.M.C., and Lieut.-Colonel E. H. Starling, and the foundations were then laid of an anti-gas department. The anti-gas department, which was to control both the design and commercial production of respirators and other defensive equipment, was under the direction of Colonel W. H. Horrocks, assisted by a small anti-gas committee composed of officers of the medical services, an officer representing the Ordnance Department, and civilians with expert knowledge of chemistry, physiology, and pharmacology. Better knowledge regarding the toxicity and mode of action of different poisonous gases was urgently required, and a physiological committee appointed by the Royal Society to deal with this question, with the aid of various other physiologists, was able in the course of the next few months to provide much useful information, both with regard to the pathological lesions caused experimentally by chlorine, and also with regard to the poisonous action of many other gases and chemical compounds that were already known and might conceivably be used by the enemy.

The task which faced the anti-gas department was a formidable one. It will be seen below that the evolution of the respirator was gradual and continued throughout the whole war ; modification succeeded modification and type succeeded type as improvements in the general structure of the respirator or in the nature of the chemical absorbents suggested themselves. The constant aim was to forestall any possible new developments of German offensive methods by increasing the efficiency of the respirator, and the success that attended these efforts may be judged from the fact that the British troops had been furnished with good protection against phosgene before the Germans first used this gas, that the respirator had been fitted with a filter to stop particulate clouds before the Germans introduced Blue Cross shell, and that when mustard gas made its appearance the respirator was proof against this gas.

Every alteration in the respirator was the result of detailed and careful investigation, and had to fulfil stringent tests before it could be accepted, close liaison being maintained between the anti-gas department and those who were responsible for protective measures in the field so that every point of view should be represented. Samples of every new device, whether made on the initiative of those working in London or suggested by the officers of the anti-gas services in France, were sent out to France before manufacture was started on a large scale, so that an opinion could be formed as to its value under the arduous conditions prevailing in the field. The organization of manufacture on a large scale was a task of great difficulty. Speed of manufacture was essential, for the number of respirators required was immense, yet the system adopted had to be an elastic one, for any changes authorized in the respirator had to be met with the smallest possible delay lest the enemy should be able to effect a surprise. The closest inspection of the different components during manufacture and of the completed respirators as they left the factories was of the utmost importance, and the smallest defect led to rejection. When a man's life depended on the efficiency of the respirator, any possibility of even the smallest quantity of poisonous air gaining entry without passing through the chemical absorbents had to be carefully guarded against. Apart from the larger defects trouble might and did arise from unduly large needle holes in the stitching of the seams of fabric helmets or from tiny holes in the masks of small box respirators, insecure attachment of eye-piece rims and mouthpieces to the fabric, or cross-threading of their screw unions, cracking of the eye-pieces, twisting or kinking of valves, perforations in the metal or soldered joints of the containers of small box respirators, slight defects in the elastic bands or tapes employed for keeping the masks adjusted. The success with which the anti-gas department was able to meet the demands made upon it for protective devices must largely be attributed to the fact that research, design, manufacture, and inspection were all finally controlled by one department: had they been separated delays and failure in supply would have been inevitable. The scale on which respirators had to be manufactured during the war can be grasped from the fact that the total number of official respirators of different types manufactured in England and supplied to the troops was fifty-five million, nineteen million being box respirators.

The daily output of protective helmets from the factories eventually reached a figure of 108,000; during August and September 1917 the weekly output of small box respirators was 70,000, and in 1918 the weekly output of these respirators increased steadily until in August it reached 200,000.

Instruction in defensive measures against gas quickly came to form an integral part in the training of all recruits in England, and to enable this to be done special officers with technical qualifications had to be appointed and schools established in the different commands. The responsibility for this training rested on the Director of Military Training at the War Office and with the General Officers in Command of Commands, Lieut.-Colonel A. Smithells being appointed Chief Chemical Adviser for training purposes to Headquarters, Home Forces.

Research on the problems of offensive gas warfare was originally carried out under the advice first of the Scientific Advisory Committee and then of the Chemical Advisory Committee of the Ministry of Munitions. Early in 1916 an experimental station was established at Porton under the command of Lieut.-Colonel A. W. Crossley to enable investigations and field trials to be carried out on a large scale. Under the direction of Mr. Joseph Barcroft, the physiologists and pathologists attached to the Porton experimental ground not only investigated the toxicology of many different poisonous gases, thus continuing and amplifying the work originally started by the Physiological Committee of the Royal Society, but they also had the opportunity of making numerous detailed researches into the pathological changes caused by the warfare gases in actual use in the field, as well as experimental investigations regarding factors of importance in treatment, investigations which led to results of direct value to those who had to deal with gas casualties. Such of these results as were not absolutely confidential in respect of their military value were embodied in printed pamphlets that were distributed, as has already been described in Chapter VII, to medical officers at home and abroad who were specially concerned with the treatment of gas casualties.

The separation of offensive research, which was under the Ministry of Munitions, from the defensive research which, together with the manufacture of respirators, was controlled by the anti-gas department under the Army Medical Department, was, however, a disadvantage. Many problems were common to both sections, and as matters stood work was liable to be duplicated unnecessarily ; the arrangement did not permit of the best and most economical use being made of the technical knowledge that was available. In October 1917, therefore, the anti-gas department ceased to be under the control of the medical services, and it was united with the offensive organization to form the Chemical Warfare Department of the Ministry of Munitions under the controllership first of Major-General H. F. Thuillier, who had been the first Director of Gas Services in France, and at a later date in the war of Brigadier-General H. Hartley. Lieut.-Colonel E. F. Harrison, who had been intimately associated with anti-gas work from the early days, was appointed deputy controller in charge of the anti-gas department.

Defensive Organization in France.

While this organization was growing up and being perfected in England the anti-gas organization in France had been undergoing rapid and extensive development A decision had soon been reached to retaliate on the Germans with gas, and it was at first suggested that the same troops that were to conduct offensive operations might also be made responsible for defensive measures. When the opinion of the Director-General of Medical Services was sought on this project strong representations were made on the extreme urgency of anti-gas defence. Attention was drawn to the fact that defence must for some time be more important than offence, since the Germans had their organization in being, while that of the British still remained to be developed. If, therefore, the proposed scheme was adopted there was a grave risk of delay in the organization of defence, since several months would be required for the training of special units for offensive gas warfare and for the provision of supplies of warfare gas. After considering the different views the Adjutant-General decided, with the concurrence of the Commander-in-Chief, that defensive measures should for the time be dealt with under the Adjutant-General in the office of the Director-General of Medical Services, and at the same time he arranged with the Director-General of Medical Services that Lieut.-Colonel Cummins, R.A.M.C., should take over all duties appertaining to defensive measures against gas, this officer being ordered to bring all correspondence daily to the Adjutant-General and instructed to keep in close touch with the officer commanding the special troops for offensive gas warfare. A scheme of anti-gas organization was at once submitted at the request of the Adjutant-General which included the establishment of a central laboratory at General Headquarters and the appointment of special officers to each army to act as chemical advisers. This scheme received the approval of the Commander-in-Chief.

The small laboratory already in existence at General Headquarters was definitely established as the "Central Laboratory" with Lieut.-Colonel W. Watson as its director, and undertook the examination of enemy material and the investigation of urgent problems met with in the field. Valuable information could thus be obtained with the smallest possible delay, though detailed investigations had to be left to the better equipped laboratories in England. The Central Laboratory gradually developed as time went on and eventually attained a considerable size. Though problems connected with gas warfare—the critical examination of defensive appliances against gas and of suggested improvements, the investigation of captured German respirators and anti-gas equipment, the examination of blind or captured German gas shell or other material for offensive use, and the analysis of the contents of gas shell—still continued to be the main concern of this laboratory, advantage was taken of its facilities for chemical and physical research to conduct other investigations, and the examination of German H.E. shell, fuses, and other captured material was constantly undertaken.

During June and July 1915 special officers with expert knowledge of chemistry were appointed to the headquarters of each army to act as chemical advisers. Their duties were to advise the staff on questions connected with gas, to give instruction to the troops in anti-gas defence, to investigate the circumstances of each hostile gas attack, to collect all relevant information, and to secure any material used by the Germans in gas warfare that might be captured. With the arrival of the army chemical advisers schools were started at each army headquarters for the purpose of giving special training to as many officers and N.C.Os. as possible in the general principles of gas warfare and in defensive measures, while lectures and demonstrations were given to units as opportunity offered when they were withdrawn into reserve or came out from the line for rest. It was, however, soon apparent that further competent assistance was needed. The division commanders were therefore requested by the Adjutant-General to appoint divisional gas officers, selected by them from infantry units, to be attached to the divisional staffs, whilst under the army chemical adviser for technical purposes. At first but few divisions made these appointments, but early in 1916 a definite establishment was authorized for divisional gas schools and the whole divisional organization was greatly strengthened and brought into close touch with the army chemical advisers. This measure proved of immense assistance.

Towards the end of 1915 it was found necessary to establish extensive re-dipping stations at Abbeville and Calais, where protective helmets withdrawn after service in the line could be washed, repaired, and re-impregnated with absorbent solution. Such helmets were then re-issued to the troops, and the wastage that would otherwise have occurred was avoided. When the fabric helmets were replaced by the small box respirators these re-dipping stations were closed down. In February 1916 a chemical adviser was appointed to headquarters, lines of communication, to supervise these establishments and to make provision for training reinforcements at the bases in the use of the respirator. In March 1916 anti-gas schools were established at the various bases, so that all draft reinforcements and men returned to duty from the base hospitals might be fitted with respirators and trained in their use. New divisions that came out complete from England had been already equipped with respirators and fully trained before proceeding overseas.

It has been pointed out that the ultimate responsibility for gas defence rested at this period of the war on the Adjutant-General's branch of the staff. Army chemical advisers were therefore responsible to the Deputy Adjutant and Quarter-masters-General at their army headquarters, while close touch was kept with the army chemical advisers by Lieut.-Colonel Cummins, who acted in the office of the Director-General of Medical Services as the direct representative of the Adjutant-General so far as defensive measures against gas were concerned, and dealt with all administrative work bearing on anti-gas defence, maintaining close liaison with the anti-gas department in England. The organization that had thus gradually developed was, however, far from ideal. It was the outcome of circumstances rather than the product of a settled and well-defined policy. Gas warfare had come as a complete surprise, yet it was clear that it had come to stay, and, what was more, was evidently capable of enormous development. The subject was a highly technical one, and though successful anti-gas defence had been rapidly developed by means of the organization outlined above it was apparent that the time had now come to adopt some more extensive scheme if the danger that threatened was to be met effectively. This fact was fully realized by those concerned with anti-gas defence, and in the winter of 1915 the Adjutant-General put forward a scheme for the union of the defensive service with the offensive under a single command. This implied transferring the defensive service from the Adjutant-General's branch of the staff to the General Staff under which the offensive service had hitherto worked. The offensive service was by this time highly developed, and the original four special companies R.E., who had liberated chlorine at the battle of Loos, were now being expanded into a brigade, and it was clear that much advantage would accrue from the union of the two services. This scheme was approved by the Commander-in-Chief and by the Army Council. On 9th March 1916, therefore, a Directorate of Gas Services was established under the General Staff with Brigadier-General H. F. Thuillier as director. This directorate was sub-divided into two branches, each under an assistant director of gas services, the offensive or " A " branch and the defensive or " B " branch. Lieut.-Colonel C. H. Foulkes, R.E., who had been in command of the special companies R.E. since their formation, became the first assistant director of gas services (A), and commander of the special brigade, while the post of assistant director of gas services (B) was filled by Lieut.-Colonel Cummins, R.A.M.C., who had been so intimately associated with the organization of defence against gas. The Central Laboratory was also brought under the same directorate. The medical services in France now ceased to have any direct connection with, or responsibility for, defence against gas, their duties so far as gas warfare was concerned lying solely in the handling and treatment of gas casualties. The supply of respirators and research on respirator design remained, however, under the control of the Army Medical Department at the War Office till October 1917. The new arrangement was of immense advantage to the defensive organization in France. The chemical advisers and divisional gas officers gained additional authority from the establishment of the directorate of gas services and the full recognition of the importance of gas warfare, while liaison with those concerned with research and production in England, both for offensive and defensive purposes, was greatly facilitated.

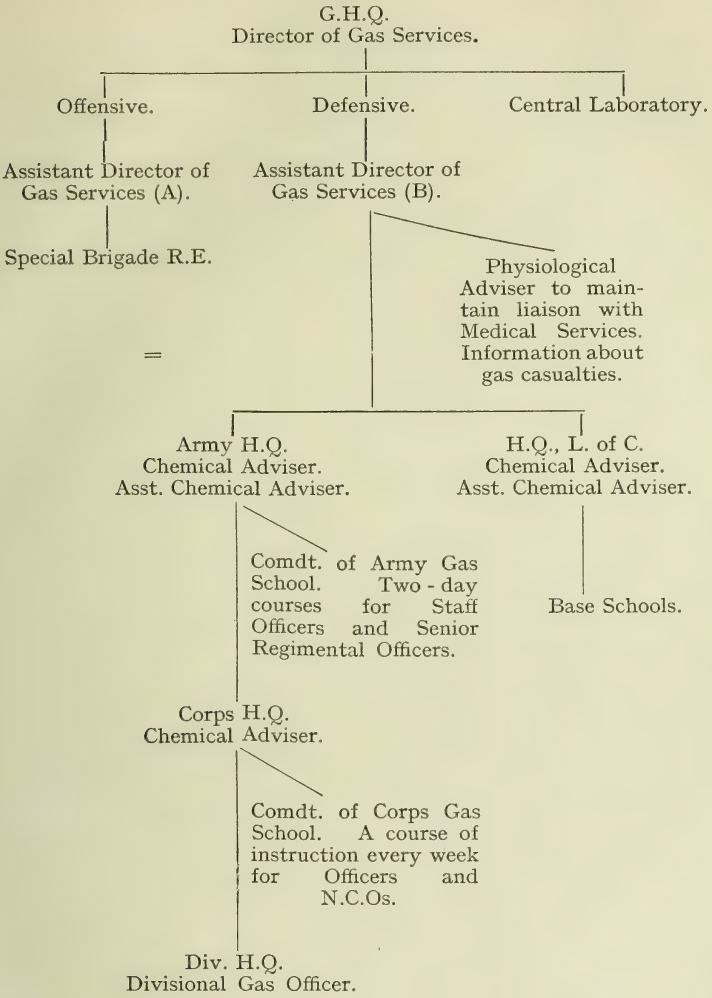
The expansion of the defensive branch of the gas services continued. In May 1917 a chemical adviser was appointed to each corps and corps gas schools were instituted, the divisional gas schools being closed down. On 17th June 1917, Brigadier-General Foulkes succeeded Brigadier-General Thuillier as director of gas services, his place as A.D.G.S.(A) being taken by Lieut.-Colonel B. L. Eddis, R.E. In July the whole of the gas services was constituted as a branch of the Royal Engineers, though hitherto this had only been the case with the special brigade, and on 18th July Lieut.-Colonel H. Hartley, R.E., an expert chemist who had hitherto been chemical adviser to the Third Army, succeeded Lieut.-Colonel Cummins as A.D.G.S.(B). So long as the post of A.D.G.S.(B) had been filled by an officer of the medical services, liaison between the gas services and the medical services had been easily maintained. This link was now lost, but to ensure that the important liaison should continue an officer of the R.A.M.C. with physiological experience, Captain C. G. Douglas, was henceforward attached as physiological adviser to the directorate of gas services.

There must always be great difficulty in appreciating the true military value of any novel departure in offensive methods until much experience has been gained, and in the case of gas warfare the number and general character of the gas casualties afforded most valuable criteria by which to estimate the degree of success attained by the German offensive methods and the efficacy of defensive measures. While the examination and analysis of data referring to gas casualties was therefore of great value to the gas services, the medical services also gained advantages from the liaison, as they could be kept in touch with experimental investigations on problems connected with gas warfare, and could in their turn suggest lines of research which would help to throw light on the pathology and on the proper lines of treatment of the gas casualties.

The physiological adviser to the gas services therefore worked in close unison with the consulting physicians of the medical services, and through the director-general of medical services was able to collect for the gas services early and complete returns of the nature and total number of gas casualties sustained in any particular gas attack made by the enemy.

The advantages of this close liaison between the medical and gas services were especially marked whenever the Germans introduced a new gas, for with the scanty existing knowledge the rapid collection and review of the clinical evidence obtained in medical units in the field was of supreme importance to both services.

The gas services reached their greatest development in 1918, and the main organization for defensive purposes is summarized in the following scheme, which shows the close connection of the defensive with the offensive branch.


G.H.Q.
Director of Gas Services.
Offensive.
Defensive.
Central Laboratory.
Assistant Director of Gas Services (A).
Assistant Director of Gas Services (B).
Special Brigade R.E.
Physiological Adviser to maintain liaison with Medical Services. Information about gas casualties.
Army H.Q.
Chemical Adviser.
Asst. Chemical Adviser.
H.Q., L. of C.
Chemical Adviser.
Asst. Chemical Adviser.
Comdt. of Army Gas School. Two-day courses for Staff Officers and Senior Regimental Officers.
Base Schools.
Corps H.Q.
Chemical Adviser.
Comdt. of Corps Gas School. A course of instruction every week for Officers and N.C.Os.
Div. H.Q.
Divisional Gas Officer.

The duties of the divisional gas officer were to advise under the general staff of the division on all questions relating to the protection of troops against gas, to supervise the anti-gas training and gas defence of units, and to collect information about the enemy's methods of gas warfare. He formed the direct link between the gas services and the units, and was assisted for the purpose of inspecting anti-gas appliances by five N.C.Os. who were distributed for duty as follows: one with each infantry brigade H.Q., one with the divisional artillery, and one with the divisional gas officer. Responsibility for gas defence rested with the commanding officer of each unit and upon the officers under him, and it was therefore requisite that as many officers as possible should attend courses of instruction at army or corps gas schools. A suitable N.C.O. who had attended a course at a corps gas school was detailed, at battalion H.Q. and in each company, to assist officers in anti-gas training, in the inspection and replacement of respirators, and in keeping in good order gas alarms, Vermorel sprayers, anti-gas fans, stocks of fuel for clearing gas from dugouts and the gas-proofing arrangements of dugouts and shelters. The company gas N.C.O. had, in addition, to make frequent observations of the direction of the wind in the company sector, take notes of the circumstances of any gas attack or bombardment, and collect specimens of gas shell or their fragments and of ground contaminated by gas for transmission to the divisional gas officer.

Defence against gas had now become a purely military problem. The task of the battalion medical officer was to look after the gas casualties ; he had no responsibility for actual defensive measures, though naturally he could advise the battalion officers regarding the nature and significance of the effects produced by the different poisonous gases, and emphasize from his experience the great value of defensive measures. It was therefore essential that every medical officer should be thoroughly conversant with defensive measures as well as with the details of the symptoms and clinical treatment of gas casualties.

Individual Protection against Gas.

On 23rd April, 1915, the day after the first German cloud gas attack, the Director-General of Medical Services arranged for supplies of sodium bicarbonate, and issued instructions that during a gas attack men should cover the nose and mouth with handkerchiefs or cloths dipped in a solution of sodium bicarbonate, which was to be kept ready for use in buckets in the trenches. Soon afterwards it was pointed out that if nothing better was at hand respirators could be extemporized from cloths moistened with urine, or earth folded in a cloth or contained in a bottle from which the base had been removed, so as to permit a man to breathe back and forth through it. On 28th April the first sample of a German respirator was received at General Headquarters, and was found to consist of a gauze bag containing a pad of cotton waste soaked in a solution of sodium hyposulphite and sodium carbonate and provided with tapes so that it could be tied over the nose and mouth. Arrangements were at once started in England to manufacture in quantity an official respirator of similar type for the British troops.

This so-called " veil respirator " (Fig. 1) was made of a long piece of black veiling folded on itself so as to contain a pocket, in the centre of which was placed a pad of cotton waste wrung out in a solution consisting of sodium hyposulphite 100 parts, sodium carbonate crystals (washing soda) 40 parts, glycerine 15 parts, and water 100 parts. Owing to the hygroscopic properties of the sodium hyposulphite and the glycerine the respirator remained sufficiently moist and did not have to be dipped in any solution before use, and it was supplied in a waterproof case to prevent it from becoming unduly dried by the sun or sodden by the rain. The pad was held in place over the nose and mouth by tying the ends of the veiling behind the neck, a free fold of the veiling being drawn up so as to cover the eyes, since it had been found experimentally that a layer of veiling materially hindered the diffusion of lachrymatory vapours into the eyes. There was some delay at first in making this respirator, since owing to an error caustic soda had been substituted for the sodium carbonate

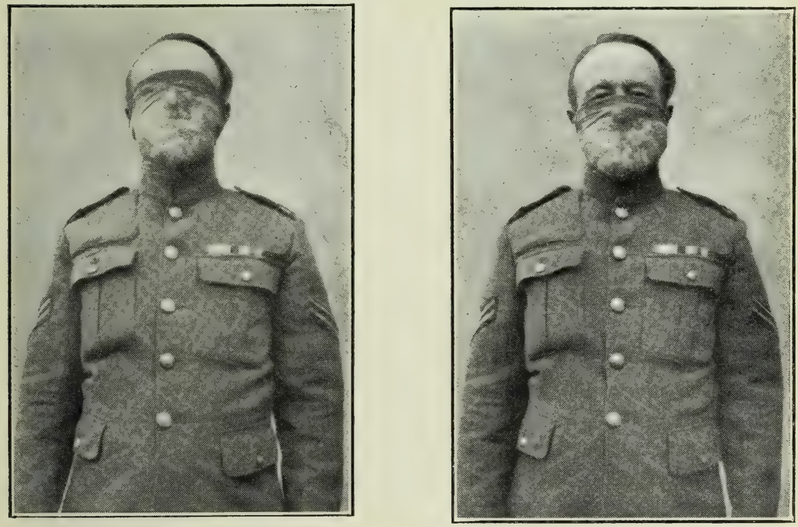

(*a*) (*b*)

Fig. 1.—British veil respirator. (*a*) Eyes covered; (*b*) eyes exposed.

specified in the solution in which the cotton waste was to be soaked, and this made the liquid too corrosive to be manipulated by the workpeople, but as soon as this mistake was rectified, manufacture progressed rapidly. Meanwhile, an appeal had been circulated through the daily press to the women of England to make respirators for the protection of the troops in France, an appeal to which there was a wide response. Unfortunately, this respirator, which was of the pad type, was made from unsuitable materials, cotton-wool and lint, which, if untreated and dry, failed to absorb the gas, and if moistened with absorbent solution hardly allowed air to be drawn through, disadvantages which did not apply to the cotton waste of the official respirator as issued. Some thousands of these respirators were actually issued to the troops, but the further supply was soon stopped, and the Director-General of Medical Services issued orders on 5th May that they were not to be used. Pending the arrival of sufficient numbers of the official veil respirator, squares of flannel cloth and cap comforters were issued on the scale of 5,000 per infantry division and 3,000 per cavalry division, to be moistened with absorbent solution and used as improvised respirators. This issue was practically completed by 3rd May. On 4th May supplies of cotton waste, veiling, and absorbent solution began to reach France, and were at once distributed to divisions to be made up locally into official type respirators ; even earlier than this some divisions had been able to obtain enough material by local purchase to start making efficient respirators. By 15th May over 200,000 veil respirators had been supplied from England, were being distributed to the troops, and were arriving in France at the rate of 60,000 daily.

In the cloud gas attack of 24th May a great number of the troops exposed were equipped with the official veil respirator, but there were still many who had not received this respirator or who put their trust in totally inadequate respirators improvised locally or obtained from England, in some cases from private sources. This fact served to bring home a point of vital importance, namely, the necessity for the most careful and practical instruction of every man in the use of the respirator. Some instruction, it is true, had been given, but there was in general a failure to appreciate how easy it was to make mistakes unless attention had been given to every detail. The official respirator had been designed so that it would not require damping before use, and yet many men, influenced by the earlier orders regarding improvised respirators, hastened to dip their veil respirators in absorbent solution, if that was available in the trenches, or failing that in water. Frequently they left the cotton waste so sodden that breath could only with difficulty be drawn through it, while if they wrung out the cotton waste in water they unwittingly removed most of the chemical absorbents. Cases were even known in which a man had applied his respirator to his chest on being gassed, because that was where he felt the pain, or covered his mouth only with the pad and continued to breathe through his nose. Yet, in spite of all these mistakes there was plenty of evidence that respirators had afforded a considerable degree of protection, and in many cases, in which they were properly designed and had been adjusted correctly and in time, men had passed through the gas cloud unscathed.

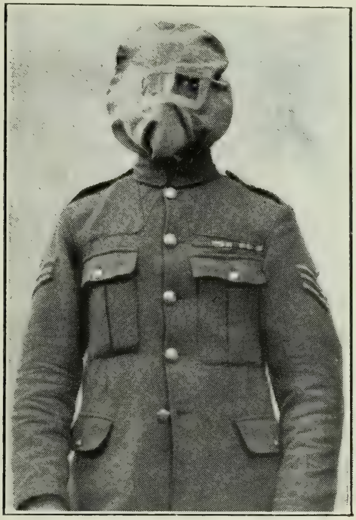


Fig. 2.—British "Hypo" or "Smoke" helmet.

The veil respirator was, however, never intended to be more than a temporary expedient, a rough but easily produced article to cope with the sudden emergency, and to be replaced as soon as possible by some more satisfactory appliance. Early in May 1915 another form of protective device had been designed in the shape of a long helmet or bag of flannel, subsequently known as the "smoke helmet" or "hypo helmet" (Fig. 2), impregnated with the same absorbent solution as was used for the respirators. This was slipped over the head, the skirt of the helmet being tucked inside the collar of the jacket so as to form an air-tight joint round the neck. A window made of transparent material in the front of the helmet permitted vision. The first supplies of this helmet that reached France were fitted with mica windows, but these proved too fragile for use in the field. A few of these helmets were being issued by 20th May to machine gunners and other men likely to be exposed to high concentrations of gas, but fracture of the mica windows rendered most of them valueless in the gas attack of 24th May, though when the windows were intact they gave good service. The supply of smoke helmets was delayed till unbreakable cellulose acetate windows could be procured, but by 4th June the supply of helmets fitted with these windows reached 10,000 per day, and the issue of smoke helmets to troops in the field was completed by 6th July. Veil respirators were still retained as a second line of defence, and one was carried by each man in addition to the smoke helmet in case the latter should be found damaged in an emergency.

Early in June 1915 the necessity was felt for some form of goggles with a view to affording better protection for the eyes against lachrymators. The smoke helmets afforded a certain amount of protection since some of the lachrymatory vapour was absorbed by the fabric, but it was inconvenient to wear them for a long time merely as a protection for the eyes against low concentrations of lachrymator vapour emanating from ground contaminated by previous shelling. It proved by no means easy to design a suitable pattern. The first type supplied consisted of an oblong piece of waterproof paper or fabric backed with flannel and fitted with two cellulose acetate eye-pieces, which could be tied by tapes over the eyes, but it never proved effective. Later in the year a more satisfactory type was produced in which glass eye-pieces were held in a metal or waterproof fabric frame and were surrounded on the side nearest the face by thick rings of rubber sponge. These so-called " rubber sponge goggles " were kept in place with the rubber sponge pressed against the periphery of the orbit by means of an elastic loop passing round the back of the head.

The veil respirators and the smoke helmets, though excellent for stopping chlorine or strongly acid gases, were of little use for absorbing other poisonous gases, and it was felt from the start that it was only a question of time before the Germans would employ some gas that would penetrate these protective devices. The gas that seemed likely to be used was phosgene, for it was known to be very poisonous, and the Germans had for long been producing this substance in quantity in their dye industry. The first experiments made in England to get a better idea of the toxicity of this substance gave somewhat misleading results, but repetition of these experiments soon established the fact that phosgene was far more dangerous than chlorine. A suitable absorbent, which was at the same time quite effective against chlorine, was found in a solution of sodium phenate, a compound of phenol (carbolic acid) with caustic soda, containing slight excess of free caustic soda. The strongly alkaline nature of this reagent would also afford good protection against hydrocyanic acid, should this be used by the Germans.

In adopting alkaline sodium phenate as the main protective agent an alteration of the helmet was necessitated, since carbonation of the alkali by the carbon dioxide in the expired air would very greatly reduce its power of neutralizing phosgene or hydrocyanic acid, and the flannel of which the smoke helmets were made would not stand its caustic action. "P-helmets" or "tube helmets" were therefore designed of the same general shape as the smoke helmets. They were made of flannelette, which was more resistant than flannel. They were wrung out in sodium phenate solution to which enough glycerine had been added to ensure that the fabric should remain sufficiently moist, the single large cellulose acetate window being replaced by two glass eye-pieces held in metal frames, and better adapted to stand rough usage in the field (Fig. 3). The essential new feature in these helmets was the provision of a metal tube penetrating the fabric opposite the wearer's mouth, the outer end of which was guarded by a rubber non-return valve of simple type which allowed expired air to be blown out through the tube but prevented air from being sucked inwards. This valve was formed of a tube of thin rubber flattened at the outer end, with slits on either edge of this flattened portion. Air could easily be blown outwards through these slits, but any attempt to suck air in through the tube was stopped by the collapse of the flattened portion. When the helmet was adjusted the wearer held the inner end of the tube in his mouth, inspired through his nose or through his mouth, in the latter case holding the tube in his teeth, and expired through the tube. The inspired air was drawn from the interior of the helmet and had therefore been freed from poisonous gas by passage through the fabric, but the expired air passed directly to the outside and the rapid carbonation of the chemical reagents in the helmet was thereby prevented. A further advantage of the expiratory valve was due to the fact that expired air did not accumulate in the interior of the helmet at the end of each breath to be re-breathed at the next inspiration, and for this reason the P-helmets were less stuffy and less likely to cause undue panting on exertion than the smoke helmets. The P-helmet was kept in a waterproof cover to protect it from rain or sun and to hinder access of air which would lead to gradual carbonation, and was carried in a fabric satchel slung over the shoulder. By the middle of November 1915 the issue of one P-helmet per officer and man had been completed, the veil respirators had been withdrawn from use, and the smoke helmet carried by each man as reserve was being replaced by a second P-helmet. All ranks were therefore protected against phosgene by the time of the German cloud gas attack of 19th December, 1915.

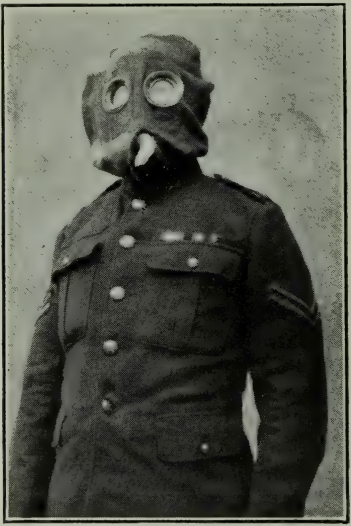


Fig. 3.—British "P" or "PH" helmet.

At the end of October 1915 a report was received from Russia that hexamine (hexamethylene tetramine or urotropine) had been found an admirable absorbent of phosgene, and experimental trials in France and England soon confirmed the truth of this. From 20th January, 1916, onwards all tube helmets were impregnated with a solution containing both sodium phenate and hexamine, and were known as " PH-helmets." Replacement of all existing P-helmets was rapid, and was practically complete by July 1916, after which date each of the fighting troops was equipped with two PH-helmets. Since the PH-helmet gave only partial protection against strong concentrations of lachrymators a proportion of these helmets known as PHG-helmets (Fig. 4) were fitted with rubber sponge goggles early in 1916, and issued to artillery units so as to ensure that gunners should not be incapacitated during a lachrymator bombardment of the batteries. The caustic properties of the sodium phenate solution in both the P- and PH-helmets occasionally led to severe blistering of the forehead or neck where the fabric came into contact with the skin ; this was more likely to occur when the heat of summer caused profuse sweating or when the helmet was unduly damp.

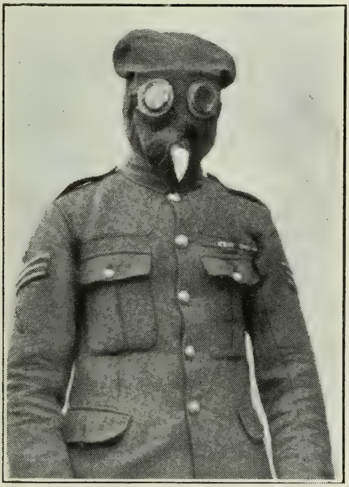


Fig. 4.—British " PGH " helmet.

Though the P- and PH-helmets gave good service, it was evident that there were serious limitations to the protection that could be afforded by this form of appliance. It was certain that if high concentrations of phosgene could be attained in the field by improvements in the methods of liberating the gas, the passage of the air breathed through a single or even a double layer of fabric soaked in an absorbent solution could not be relied upon to remove anything like the whole of the poisonous gas. Moreover, as further developments of gas warfare were evidently to be expected, there was every reason to think that the Germans would soon introduce new gases with which the chemicals in the PH-helmets would fail to react ; as it was, the simple lachrymators were only partially stopped by the existing helmets. The fabric was far from an ideal substance on which to support the chemical absorbents, for such absorbents were practically bound to be applied in solution, and the fabric could only take up a limited amount, while multiplication of the absorbents to deal with different gases might easily be defeated by their chemical interaction or by their corrosive character. It had been suggested from the earliest days of warfare gas that the best method to adopt would be that of breathing through a box or canister, which would admit of chemical absorbents being employed either as solid granules or as liquid held by absorption in some porous material. With such an arrangement it would be easy to add to or alter the absorbent chemicals, and the risk of chemical interaction between the different ingredients could, if necessary, be overcome by separating them into different layers in the canister. Deterioration of the absorbents from the action of moisture or carbon dioxide in the expired air could be avoided by fitting the apparatus with valves so that the inspired air alone could be drawn through the canister, the expired air being directed to the outside.

In the summer of 1915 very efficient granules composed of lime and sodium permanganate had been experimentally produced and tested in a simple valved canister by Mr. B. Lambert at Oxford University. Owing to the oxidizing and alkaline properties of these granules they were able to deal not only with chlorine, phosgene, and hydrocyanic acid, but also with other gases of an acid character or gases capable of easy oxidation such as arseniuretted hydrogen, against which gas the various helmets were of no avail. Moreover, the ordinary lachrymators were to a great extent removed from the air by adsorption on the surface of the granules. The foundation of the future box respirator was thus laid, but difficulties encountered in the design and manufacture of a suitable type of apparatus, built as it was bound to be of many component parts, and in the commercial production of efficient granules, had to be overcome before the use of this appliance in the field became practicable. The earliest issue of a respirator of this type, the " tower " or " large box " respirator, was made in the winter of 1915–1916 to the special brigade R.E. for use during British gas operations when there was a risk of encountering very heavy concentrations of gas. The canister was of large size, and contained three layers of absorbents, lime-permanganate granules, fragments of pumice soaked in sodium sulphite solution, and fragments of animal charcoal. The sodium sulphite was added to increase the protection against chloropicrin, and the charcoal was employed owing to its well-known properties as an adsorbent of gases and a catalytic agent for many chemical reactions. The canister was carried slung in a satchel, and at the bottom was fitted with a simple inspiratory valve. A flexible rubber pipe of large bore led from the top of the canister to a metal mouthpiece which was surrounded by a small mask composed of a number of layers of fabric soaked in the solution used for the PH-helmets. A simple rubber expiratory valve was inserted in the metal mouthpiece just outside the attachment of the mask. When the mouthpiece was held in the mouth the mask was kept firmly applied to the face, so as to enclose the nose and mouth, by rubber bands passing round the back of the head, while the nostrils were closed by a metal clip fixed in the fabric of the mask. The wearer could therefore breathe only through the mouthpiece. A pair of rubber sponge goggles completed the equipment. The apparatus proved so successful that in February 1916 it was decided to issue 7,500 large box respirators to each army for the use of machine gun personnel and selected officers and men of the artillery, who were regarded as of supreme importance for preserving the integrity of the line in the event of a sudden attack.

Meanwhile attention was being concentrated on the design of a box respirator suitable for universal use in the field. It was decided to fill the canister with both lime-permanganate granules and good quality animal charcoal, the granules forming a layer between two layers of charcoal. The granules themselves did not act as very good absorbents of chloropicrin, but this defect was overcome by the addition of the charcoal, and so effective was the combination found that the bulk of the canister could be greatly reduced, and in spite of this the absorptive power be maintained at as high a level as in the original large box respirators, heavy lachrymator vapours as well as lung irritant gases being effectively stopped. There remained one difficult problem to be solved, namely, to design a respirator that would allow the wearer to talk and give orders in a poisonous atmosphere without running any risk of inhaling gas. Provided that the wearer of the respirator did not require to speak it was easy to ensure safety in such an atmosphere by stopping the passage of air through the nostrils by a spring clip and fitting the end of the metal mouth tube with a rubber mouthpiece bearing a wide flange arranged to lie between the lips and teeth. Mouthpieces of this type had frequently been used by physiologists engaged in respiratory problems and had been found to give a reliable air-tight joint; they had also been used on mine rescue apparatus and their safety proved under the severe conditions obtaining in a mine after a fire or explosion. The arguments in favour of a flanged mouthpiece were so strong that it was decided to incorporate it in the new respirator and maintain it at all costs. It was finally resolved to copy the impermeable face-mask of the respirator recently adopted by the Germans as their standard protection, for the fullness of the fabric of this mask allowed sufficient play for the easy withdrawal and replacement of the

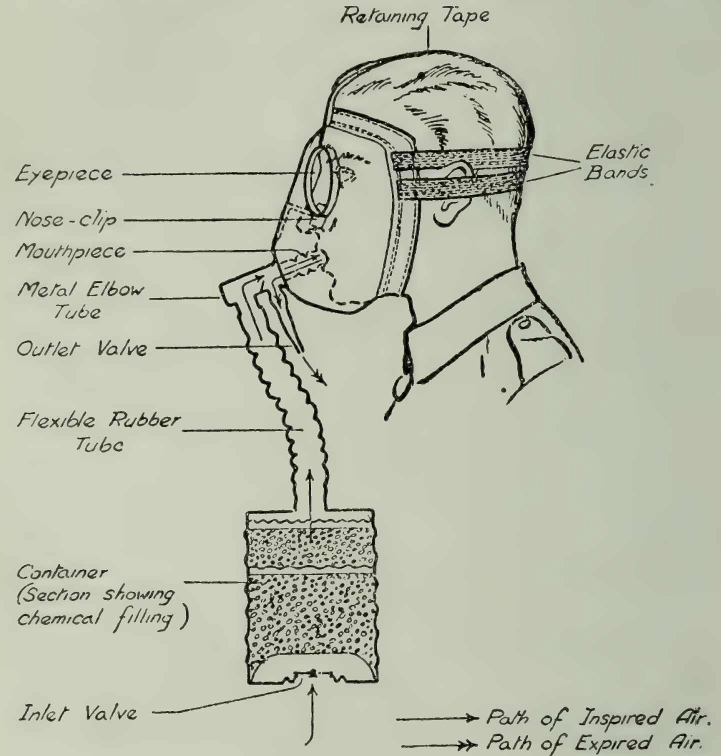


Fig. 5.—Diagram of the construction of the British small box respirator.

flanged mouthpiece, while the tight fit of the edge of the mask to the face prevented poisonous air from gaining entry while the wearer was speaking.

The final design adopted for the British " small box respirator " is shown diagrammatically in Fig. 5, and illustrated in use in Fig. 6. The canister, or " container " as it was officially called, was fitted at the bottom with a simple inlet valve formed by a rubber disc held by a stud in the centre of a perforated metal plate. A dome-shaped piece of wire gauze placed above the inlet valve served to support the charcoal and lime-permanganate granules. Above the granules was a layer of Turkish towelling to prevent any dust from the granules being inhaled, and over this a layer of wire gauze between which and the top of the canister was inserted a metal spring to ensure that the granules were kept from shaking about, for this might easily lead to the formation of channels through which air might be drawn without making sufficient contact with the chemical absorbents. Undue packing of the granules, which might lead to an increase in the resistance to the passage of air, was hindered by the insertion of two layers of wire gauze in the middle of the granules, and these served also to separate the lime-permanganate from

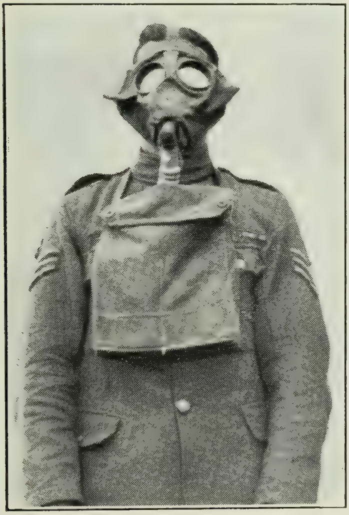


Fig. 6.—British small box respirator.

the charcoal layers. A flexible rubber tube, strengthened on the outside by fabric, led from the top of the container to a metal elbow tube which penetrated the face-mask by means of an air-tight joint and terminated in a flexible rubber mouthpiece fitted with a labio-dental flange. An expiratory valve made of rubber, and similar in type to that used on the tube helmets, was inserted in the metal elbow between the mask and the entrance of the inspiratory tube from the container. The face-mask itself was made of impermeable rubbered fabric, and was held in position by means of elastic bands and a retaining tape as shown in the diagram, an air-tight joint being formed by the close fit of the edge of the mask to the forehead, to the sides of the face just in front of the ears, and underneath the chin. Two circular eye-pieces of celluloid were fitted air-tight into the mask by means of metal rims, and beneath these was attached a spring nose-clip that could be opened at will by pressure from the outside. Folds in the fabric of the mask immediately behind the eye-pieces could be pushed in by the finger to wipe condensed moisture from the inside of the eye-pieces ; an anti-dimming preparation consisting mainly of hard soap was also supplied with each respirator, and when the eye-pieces were polished with this there was far less tendency for them to become cloudy. When once the face-mask had been adjusted and the nose-clip applied the wearer had merely to breathe back and forth through the mouthpiece ; both eyes and lungs were effectively protected from poisonous gas. At first salivation owing to the presence of the mouthpiece in the mouth proved a troublesome feature as the saliva was liable to find its way down the flexible rubber tube into the container and cause deterioration of the absorbents, but this difficulty was met by inserting a small upstanding flange in the metal elbow tube on the far side of the opening for the expiratory valve to act as a trap and divert saliva out through this valve. The small box respirator was carried ready for use in a haversack fitted with two compartments, the container resting in one compartment and the face-mask in the other. In the so-called " alert-position " of the respirator —a position which had to be assumed before the respirator could be used, since the container was strapped into the haversack—the haversack and its contents were hung in front of the chest, the sling, shortened by the aid of a buckle or other simple device, passing round the back of the neck ; the haversack was prevented from shifting by passing a piece of whipcord round the waist and fastening it to two rings fixed on either side of the haversack. In order to gain protection all that was now necessary was to pull the mask from the haversack, adjust it in position over the face, place the mouthpiece in the mouth and fix the nose-clip on the nose. In areas in which the troops were constantly exposed to the danger of gas the small box respirator was always carried in the "alert position," for full protection could then be secured within a second or two on receiving an alarm, while it interfered little with a man's equipment and did not interfere with his work.

The small box respirator afforded two lines of defence to prevent the entrance into the lungs of poisonous air which had not passed through the chemical absorbents. There was firstly the air-tight joint of the mouthpiece with the mouth, and secondly the air-tight joint between the edge of the mask and the face. In the German respirator entire reliance was placed on the second of these, but the British felt that security could not be sufficiently guaranteed by this method alone. Displacement of the mask by accidental blows, or even by movements of the face or jaws, might, it was felt, lead to leakage at one or more points of the joint, and before this could be rectified sufficient gas might have been taken in to start a bout of coughing, which would be only too likely to displace the mask still further and cause the wearer to fall a victim to the poisonous atmosphere; moreover, there was always the risk that the fabric of the mask might become torn or perforated. Though the eyes would of course be affected in these circumstances the far more serious damage to the respiratory system would be prevented by the mouthpiece and nose-clip. For these reasons the British adhered to the double protection throughout the war, except in certain special cases, which will be mentioned later, regarding the enhanced security as far outweighing the irksomeness of wearing a nose-clip and breathing through a mouthpiece. Great care was, however, taken to ensure that the joint between the edge of the mask and the face should be as air-tight as possible; several different sizes of mask were supplied and each man was fitted individually, the fit being proved by exposing the man with his respirator adjusted to lachrymator vapour in a gas chamber for five minutes, at the end of which time no irritation of the eyes should have occurred.

The manufacture of small box respirators on a commercial scale was started in June 1916, and in the middle of August issues were made to army and divisional gas schools so as to allow preliminary instruction in the use of the appliance. On 27th August authority was given for the issue of small box respirators to the Second Army on the scale of one per officer and man, and by 19th September 172,600 small box respirators had been issued to this army. Thereafter, small box respirators were issued in succession to the First, Third, Fifth, and Fourth Armies, issue being completed by the end of January 1917. All large box respirators and PHG-helmets were withdrawn, and the anti-gas equipment of each of the fighting troops now consisted of a small box respirator and a reserve PH-helmet. It had been intended that each man should in addition retain a pair of rubber sponge goggles to protect the eyes from such concentrations of lachrymator vapour as were insufficient to necessitate wearing the entire respirator. As, however, the Germans had since the commencement of the battle of the Somme been making increased use of lethal gas shell which had quite considerable lachrymatory properties, goggles alone had practically become useless as a protection, and their retention could in fact only be a source of danger; they were therefore withdrawn. For the future the respirator had to be put on without paying any regard to the precise nature of the gas bombardment.

In the winter of 1916–1917 the question of protection against clouds containing matter in the particulate and not in the gaseous state was taken up. Attention had been called to this problem, since it was found that the cloud liberated from British trench mortar bombs filled with stannic chloride was largely in the particulate state, and was capable of penetrating the existing small box respirator and causing pulmonary irritation. While a great number of poisonous gases and vapours could readily be removed from air by adsorption on charcoal or by interaction with chemical absorbents, this was not the case with matter in the particulate state. To hold back a particulate cloud nothing short of mechanical filtration was found effective, and great difficulty was experienced in finding a satisfactory filtering medium. By the end of March 1917 a supplementary canister or " extension " had been designed for the small box respirator, and was being sent out to France for trial. This extension consisted of a small box with an inspiratory valve in its bottom above which was the filter composed of a number of layers of cellulose wadding, the remainder of the box being filled with lime-permanganate granules which would increase the efficiency of the respirator against hydrocyanic acid, a matter thought desirable at this time. The top of the extension was fitted with a wide, slightly conical tube which could be pushed home into the circular opening left in the bottom of the container of the small box respirator after prising out the perforated plate carrying the inspiratory valve. These extensions were issued to the Second and Fifth Armies and the XVth Corps between April and June 1917, and consequently forestalled the introduction by the Germans of gas shell capable of liberating a particulate cloud, for the first bombardment with Blue Cross shell did not occur till 10th July. While the filter stopped the Blue Cross substances, the charcoal and granules proved perfectly efficient as absorbents of mustard gas when Yellow Cross shell made their appearance.

The extension was, however, only a temporary expedient. A new pattern container, known as the NC-container, had meanwhile been designed. No extension was necessary with this container, for the cellulose wadding filter was incorporated in it, yet in spite of this its bulk was no larger than the old container, for continuous research had resulted in the production of wood charcoal and lime-permanganate granules of much increased absorptive power. Charcoal and granules were now mixed together instead of being arranged in separate layers. NC-containers began to arrive in France in the middle of August 1917, and by the end of the year the replacement of all old pattern containers had been completed. With a view to giving still greater protection against particulate clouds jackets formed of fabric backed by a number of layers of cellulose wadding and shaped to fit over the NC-container, so as to filter the air before it entered the container, were designed early in 1918. A certain number was issued for use in the field at the commencement of April 1918, but as the Germans used in their great spring offensive no new or more effective methods for liberating particulate clouds than they had employed in 1917, the jackets were withdrawn at the beginning of May and stored at bases for use in case of emergency.

A further improvement made in the small box respirator was the substitution from March 1918 onwards of splinterless or " triplex " glass eye-pieces in place of those made of celluloid, for this allowed much clearer vision. The small box respirator with glass eye-pieces and NC-container remained in use till the end of the war as a general issue, but two modifications were introduced to meet special circumstances. Crews of tanks found that vision was so difficult when they were in the tanks that it was most desirable not to impede it further by the face-mask, and a small box respirator, fitted with a mouth mask and with separate goggles, was therefore issued to them, while shortly before the end of the war a demand had to be met to supply anti-aircraft gunners with respirators arranged on the French Tissot principle, as it was imperative that the eye-pieces in this case should never become clouded by condensation of moisture so as to obscure vision even momentarily. The PH-helmet afforded no protection against either the arsenical warfare gases or mustard gas, and the reserve PH-helmet, which had till then been carried by each man, was finally withdrawn in February 1918. In the last ten months of the war the sole protection against gas carried by each man was the small box respirator, and so effective was the NC-container that, when new, it would protect the wearer against a concentration of one part of phosgene in one hundred of air for half an hour or even longer.

The effective life of any respirator was a limited one, for the chemical absorbents deteriorated with time, and the rate of deterioration was accelerated by breathing through the respirator. As it was essential to train the troops continually in the use of the respirator and to accustom them to wear it whilst carrying on their ordinary military duties, stringent rules had to be laid down as to the length of time that could be allowed to elapse before replacing the respirator. If the respirator was worn in gas this time was, of course, curtailed, and after a cloud gas attack all respirators which had been used were withdrawn at once and replaced. Respirators, too, were liable to develop defects and were subject to accidental injury, and to guard against these very frequent and careful inspection was necessary. Unless the defect was so trivial that a repair could be effected on the spot it was necessary to replace the faulty respirator, and to ensure that there should be no delay in doing this, small reserves of respirators and containers were held by units, and a much larger reserve by divisions, the reserves being continually replenished from the base. Wastage of respirators was unavoidable, though every effort was made to keep this wastage down to the minimum by the renovation of used or damaged respirators ; if the container of the small box respirator became defective or had been breathed through for the specified time (a total of forty hours in the case of NC-containers), the container alone was replaced, provided that the rest of the apparatus was in good order, and this could be done in the unit by a gas N.C.O.

Though the eyes and lungs could be protected against mustard gas by the small box respirator, the blistering action on the skin had still to be reckoned with. Heavy oilskin garments were the only articles that were found to give effective protection in this connection, but their weight and oppressiveness rendered them impracticable for general issue in the field, though they were of value in a few isolated cases. In handling clothing, equipment, weapons, or material contaminated with mustard gas, protection of the hands could be secured by wearing thick leather gloves treated with oil, a pair of cotton gloves being worn outside these so as to enable a better grip to be obtained.

No form of respirator employed by the British was of the slightest avail against carbon monoxide. The tunnelling companies who had frequently to face this gas were equipped with special oxygen-breathing or mine rescue apparatus, which rendered them completely independent of the atmosphere. In the early days of gas warfare a limited trial of similar apparatus had been made with a view to protecting machine gunners against warfare gas, but it proved far too complicated and inconvenient for use by any but specially trained men, and the idea was soon discarded. When trouble arose in 1918 from carbon monoxide poisoning in closed machine gun

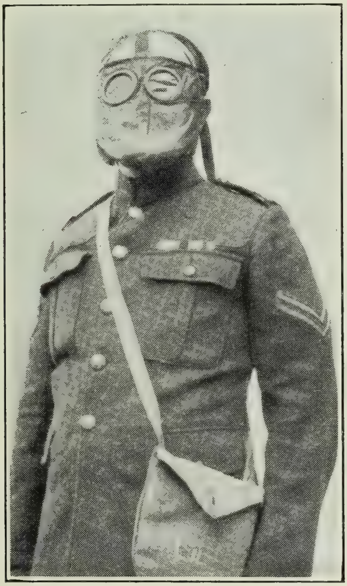


Fig. 7.—French anti-gas mask, type M2.

emplacements owing to the blow-back from the gun, the difficulty was met by providing more adequate ventilation and by fitting a parabolic cup attachment to the end of the barrel so as to deflect the blast of the gun more effectively.

The American troops were supplied with respirators identical with the British small box respirators, and British small box respirators were supplied in 1918 in considerable numbers to the Italian troops, who had previously made use of a respirator similar to the French M2 respirator. The protective appliances used by the French were different in construction from those used by the British, and fell in the main into three types :—

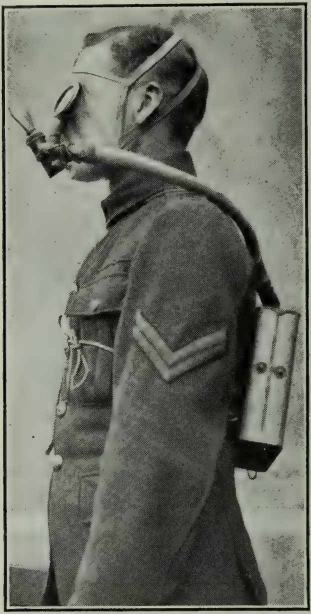


Fig. 8.—French respirator, Tissot pattern.

(*a*) An anti-gas mask for universal use (Fig. 7), or type M2, formed of a number of layers of fabric treated with chemical absorbents, and held in position by elastic bands passing behind the back of the head and neck so as to cover the whole face, a pair of transparent eye-pieces being inserted opposite the eyes.

(*b*) The Tissot apparatus for use by special troops (Fig. 8), *e.g.*, machine gunners and artillery personnel, in which a large canister containing the chemical absorbents, and perforated at the bottom for the entrance of air, was supported on the back and connected by a flexible tube passing over one shoulder with a face-mask of grey rubber or impermeable fabric fitted with eye-pieces. An inspiratory valve was placed at the junction of the flexible tube and the canister, and the tube itself was forked at its entrance into the face-mask and so designed that the relatively dry air that was drawn into the mask at each inspiration impinged upon the inner surface of the eye-pieces, an arrangement that effectively prevented the eye-pieces from becoming dimmed with condensed moisture. A tube bearing an expiratory valve was inserted in the front of the mask. There was no mouthpiece or nose-clip, and the wearer after adjusting the mask merely breathed back and forth into it ; entire reliance was placed on the close fit of the edge of the mask to the face.

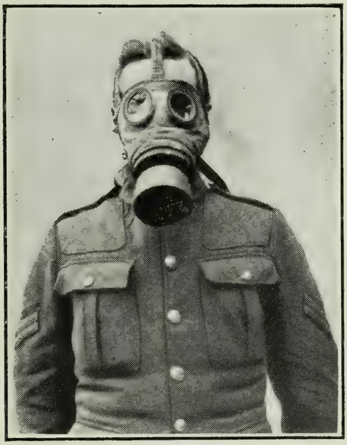


Fig. 9.—French A.R.S. respirator.

(*c*) The A.R.S. apparatus for universal use (Fig. 9), which in the later period of the war supplanted the M2 mask. Outwardly this resembled the standard German respirator. It consisted of a drum containing the chemical absorbents which screwed into a shallow box fixed into the lower part of an impermeable fabric face-piece fitted with eye-pieces, the box containing both inspiratory and expiratory valves so arranged that the inspired air drawn through the drum into the interior of the face-mask was directed upon the inner side of the eye-pieces on the Tissot principle, while the expired air passed direct to air without passing through the drum. Again there was neither mouthpiece nor nose-clip.

The Germans, who had used a simple pad respirator impregnated with sodium hyposulphite and sodium carbonate in their earliest cloud gas attacks and subsequently a form of mouth-mask, had at the time of the battle of Loos just begun to introduce a type of respirator which remained their standard protection throughout the war. It consisted (Fig. 10) of a face-mask of impermeable rubbered fabric (which later served as a model for the mask of the British small box respirator), fitted with two celluloid or cellone eye-pieces held in metal rims. A metal plate was fitted air-tight into the lower part of the face-mask and into this was screwed a drum containing the chemical absorbents. There were neither valves, mouthpiece, nor nose-clip. Entire reliance was placed on obtaining an air-tight fit of the mask to the face by means of elastic bands passing round the back of the head, and when once the mask had been adjusted the wearer breathed into the mask,

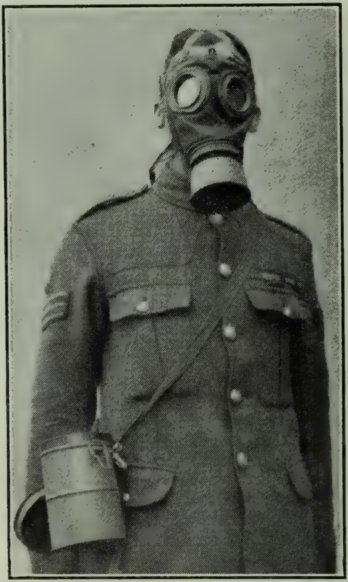


Fig. 10.—German respirator.

the air respired passing back and forth through the drum. The provision of folds in the fabric of the mask allowed the inner side of the eye-pieces to be wiped clear of condensed moisture. The absorbents in the drum were arranged in three layers, an inner layer composed of fragments of brick or other porous material impregnated with hexamine and potassium carbonate, a middle layer of charcoal, and an outer layer of pumice or brick impregnated with potassium carbonate. Each man carried a spare drum in addition to one screwed into the mask ready for use, the respirator being carried slung in a protective metal box. No substantial changes in the design of this respirator were made subsequently, though there were some alterations in detail. In the summer of 1917 heavily oiled leather masks began to be substituted for those made of impermeable fabric, and as these did not admit of folds for wiping the eye-pieces the celluloid eyepieces were backed with non-dimming gelatine discs, the latter being protected from being rubbed by a light metal grid. From the spring of 1918 onwards the filling of the drums consisted of only two layers, an inner of hexamine and potassium carbonate on brick, and an outer of charcoal of very high absorptive power. The attacking troops in the German offensive on 21st March, 1918, were equipped with a perforated metal cover containing a disc of filter paper which could be clipped over the outer end of the drum. The intention of this was to afford protection against particulate clouds, whether derived from their own Blue Cross shell or from British shell containing stannic chloride. The issue of these covers subsequently became general, but they afforded little protection against a particulate cloud though they greatly increased the resistance to breathing through the drum. In the later period of the war it was customary to find coiled metal springs substituted for elastic in the bands to hold the face-mask in place, a modification necessitated by the shortage of rubber. The drum was of relatively small size compared with the container of the British small box respirator, and though its contents were of high quality and capable of withstanding a low concentration of phosgene for a considerable time, it failed rapidly in high concentrations; even the best German respirators captured in 1918 allowed a serious amount of gas to penetrate within one to two minutes when tested in a concentration of one part of phosgene in one hundred of air.

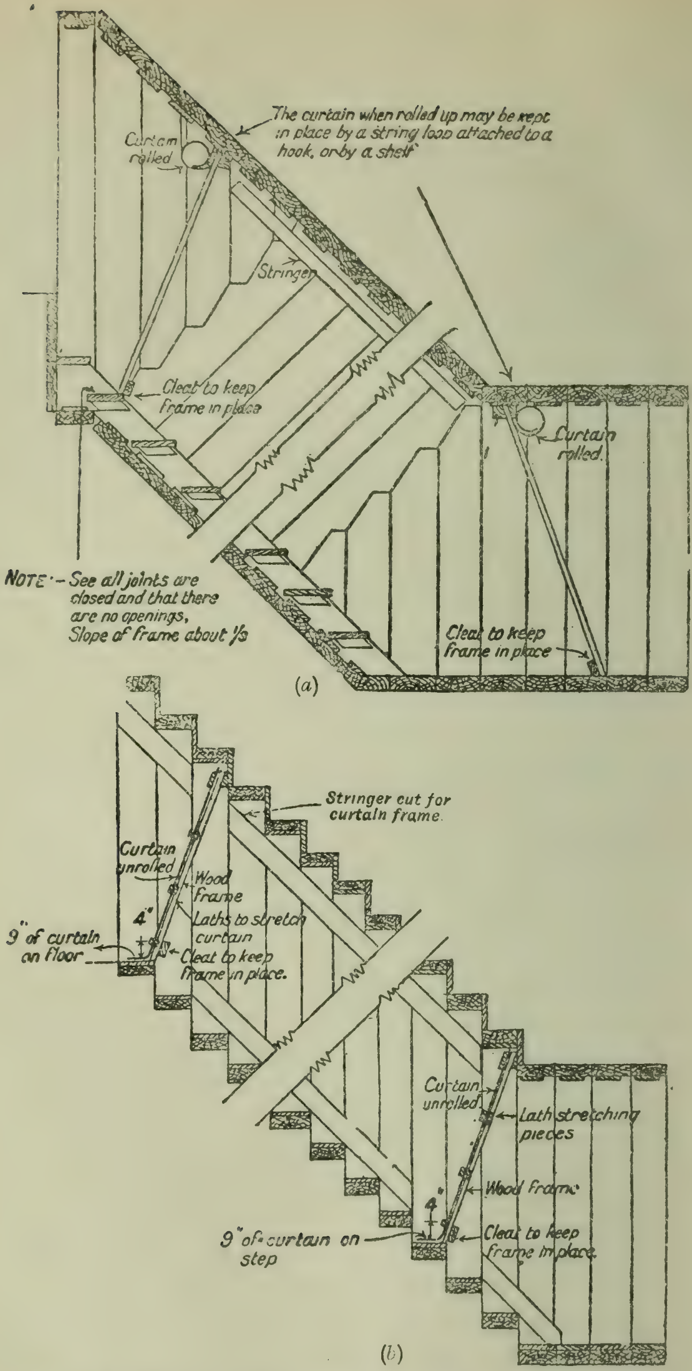
Though horses were vulnerable to warfare gas they could in general stand with impunity higher concentrations than were tolerable for man. In order to reduce the risk of serious casualties amongst transport animals that were sent to the vicinity of the trenches or batteries with supplies or ammunition, and therefore ran the risk of meeting a concentrated gas cloud or heavy gas shelling, respirators were designed to protect the lungs. The British, French, and Germans adopted for this purpose respirators of closely similar type, namely, a long bag of fabric treated with a chemical absorbent and stiffened with canvas or other material so that it should not collapse against the nostrils when in use. The British horse respirator was impregnated with the solution used for the PH-helmets and was designed so as to enclose the nostrils only, the lower edge of the opening of the bag being slipped into the animal's mouth and pulled up to the angle of the lips, when the opening of the bag could be drawn tight round the upper jaw just above the nostrils. Casualties arising from the acute lung irritant gases did not, however, occur in any great number amongst transport animals, and as the respirators proved troublesome in use they were discarded by the British in the final stages of the war.

Collective Protection against Gas.

In connection with collective protection against gas certain measures, such as local and general meteorological observations, arrangements for spreading the gas alarm, and the protection of weapons and equipment from the corrosive action of gases, may be regarded as purely military questions. The protection of dugouts from gas, and the methods of clearing gas from dugouts and trenches were, however, factors which were of direct assistance in reducing materially the number and severity of gas casualties, and therefore demand consideration.

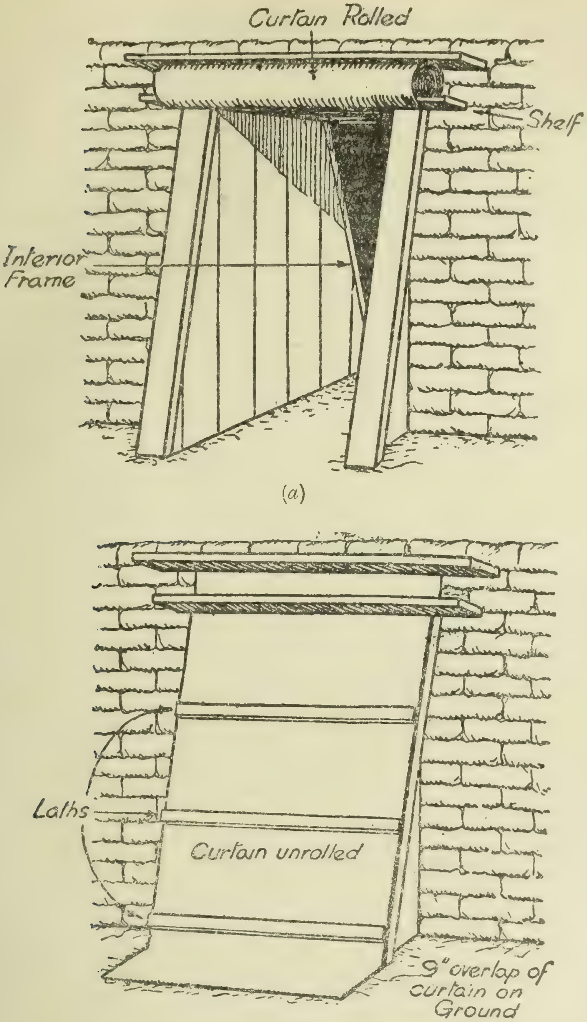
All dugouts, shelters, cellars, and dressing stations had to be protected as far as possible against the entrance of gas. When this was done successfully the occupants could leave off their respirators, though strict watch had always to be maintained to note the first sign of the penetration of gas, when respirators had to be adjusted immediately. Protected dugouts were of the greatest value in areas bombarded with gas shell of high persistence, for otherwise it would have been necessary to wear the respirator in the area in question for long periods. The method employed for rendering a dugout gas-proof is shown in Figs. 11 and 12. A sloping wooden frame was fitted at the entrance, and over this was hung a curtain made from a blanket or from special fabric, a fair air-tight joint being ensured by cutting the curtain wide enough to overlap the frame and of sufficient length for about nine inches to rest on the ground. The curtain could be kept stretched to the right width by nailing laths across it at intervals, or could have weights fixed to its edge to hold it in place. When not in use the curtain was rolled up to preserve it from damage, and secured to the top of the frame. If the structure of the entrance to the dugout permitted it two such curtains were used, one at the entrance, the other a few feet behind in the passage or stairway, so as to form an air-lock between them. When anyone wished to enter or leave such a dugout during a gas attack he passed through the first curtain, dropping it carefully in position behind him, and not till he had done this did he raise the second curtain. This arrangement was intended to ensure that a minimum of gas should gain entry into the dugout as a man entered or left, a purpose that was, however, frequently defeated by men dashing through the curtains, leaving them displaced or torn, in their hurry to gain shelter from sudden heavy shelling. In the case of aid posts and dressing stations the air-lock between the two curtains had to be made of greater length so as to allow stretcher cases to be carried in. Gas was found to diffuse extremely slowly through the thick material used for the curtains, provided that they were kept moist with water, or still better with the weak hyposulphite solution used in Vermorel sprayers or with solution of calcium chloride. Towards the end of the war curtains treated with heavy mineral oil were coming into use ; these proved very successful and did away with the necessity for damping. Precautions had to be taken to fill up all unnecessary apertures leading into the dugout or shelter, and arrangements made to block when necessary ventilating shafts, flues, and the like. Any fire that was alight in a dugout had to be extinguished directly the gas alarm was heard, lest the draught created by it should draw gas into the dugout. In a few instances when large and important dugouts had to be closed against gas for long periods in areas continually subject to heavy gas shelling, forced ventilation was adopted, air being sucked from the outside by an electric fan through a large filter filled with the chemical absorbents used in the small box respirators, and being driven into the dugout under pressure, to find its way out through the curtains at the entrances.

When a cloud gas attack or gas bombardment was over, gas which had not been driven away by the wind, but was still lurking in trenches and dugouts, had to be cleared away before


The curtain when rolled up may be kept in place by a string loop attached to a hook, or by a shelf
Curtain rolled
Stringer
Cleat to keep frame in place
Curtain rolled
Cleat to keep frame in place
(a)
Stringer cut for curtain frame.
Curtain unrolled
Wood frame
Laths to stretch curtain
4"
9" of curtain on floor
Cleat to keep frame in place.
Curtain unrolled
Lath stretching pieces
Wood frame
4"
9" of curtain on step
Cleat to keep frame in place.
(b)

NOTE:—See all joints are closed and that there are no openings, Slope of frame about 1/3

Figs. 11 (*a*) and (*b*).—Arrangement of curtains on the stairway of a deep dugout as a protective against gas.



(a)

(b)

Figs. 12 (*a*) and (*b*).—Arrangement of curtains at the entrance to a shelter or dressing station as a protective against gas.

men could enter them without wearing their respirators. As early as April 1915 specimens of portable sprayers were received from England, as it was thought that gas might be dissipated from the trenches by a fine spray of some suitable liquid. The Vermorel sprayer was selected, and large numbers were ordered. These were filled with a dilute solution of sodium hyposulphite and sodium carbonate, and were employed in trenches and dugouts after the cloud had passed. Though they proved successful when chlorine alone had to be dealt with, no effective solution could be found to cope with the other warfare gases, and when the Germans discarded the use of pure chlorine the Vermorel sprayers were withdrawn from general use for clearing out gas after an attack, though they were still retained for damping the anti-gas curtains at the entrances of protected dugouts. Towards the end of 1915 anti-gas fans began to be supplied to the troops in the trenches. The fan consisted of a square of canvas supported by braces of cane and fitted with a wooden handle ; it could be employed after the cessation of a gas attack to create a current of air and thus help to expel residual gas from trenches, shelters, or shallow dugouts, though it was of course useless while a gas attack was in progress. These fans were of service so long as the non-persistent gases had alone to be dealt with, but as the war progressed they became of less and less use, for they were not suitable for clearing gas from deep dugouts which were built in increasing numbers as the war went on, nor were they of any avail when the ground became contaminated with a persistent gas such as mustard gas. Far the most satisfactory way of clearing gas quickly from a dugout, provided always that the air outside was quite free from gas, was to create a through draught by lighting a fire in it close to the inner end of one of the entrances, or in the centre of the dugout if there was only a single entrance, and this method was regularly used in the latter part of the war.

Contamination of the ground by persistent gases was always a troublesome problem. No ready method of neutralizing the simple lachrymators was ever found, but where the contamination of the ground by previous lachrymator shelling was a serious annoyance, as in the neighbourhood of battery positions, much could be done by covering the shell craters with at least one foot of fresh earth. The problem, however, became much more serious after the introduction of mustard gas. Enormous numbers of these shell were used, and large tracts of ground were liable to be heavily contaminated and remain a danger for days. Dry chloride of lime is capable of destroying mustard gas by oxidizing it to the corresponding sulphone $(CH_2Cl.CH_2)_2SO_2$, or sulphoxide $(CH_2Cl.CH_2)_2SO$, but the quantity required rendered its use over large areas impracticable, although at important points such as the neighbourhood of headquarters, large dugouts, gun emplacements or dressing stations shell craters were successfully treated with chloride of lime. Chloride of lime sprinkled at the entrances of dugouts helped to destroy mustard gas liquid which might otherwise have been brought in on men's boots.

Contamination of men's clothing by splashes of mustard gas liquid was a source of danger not only to themselves but to their neighbours, and clothing or blankets might absorb quite sufficient of the vapour during a mustard gas bombardment to become dangerous for the time being, especially if men with clothing thus contaminated crowded together in dugouts. Clothing very slightly contaminated with mustard gas could be rendered innocuous by free exposure in the open air to the sun and wind for forty-eight hours. A still more rapid and satisfactory method of dealing with slightly contaminated clothing, and one that was employed fairly often in the later stages of the war, was to expose men who had been subjected to a mustard gas bombardment to an atmosphere consisting of one part of chlorine per one thousand of air in a gas chamber for ten minutes with their respirators adjusted; the chlorine soon caused the oxidation of traces of mustard gas in the clothing. If, however, men had been exposed to heavy concentrations of mustard gas for long periods, and particularly if their garments had been splashed by actual liquid, it was necessary to replace their clothing and disinfect that withdrawn either by several changes of hot water at 60°–80°C., or by treatment with steam in a Thresh disinfector or in a chamber of the same type as that used in delousing stations, mustard gas being saponified with water into the practically harmless substances thiodiglycol $(CH_2OH.CH_2)_2S$, and hydrochloric acid. Reserves of clothing had therefore to be held by formations.

Reference has already been made to the precautions taken to prevent food and water from being affected by gas, or from being consumed if suspected of contamination.

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CHAPTER XI.

THE ACUTE LUNG IRRITANT GASES. PATHOLOGY.

THE points where the gases classed as acute lung irritants exercise their most pronounced effect are the alveoli of the lungs and the smaller bronchial tubes, and the great danger to be feared, which is common to them all, is the onset of acute pulmonary œdema. It is in the main this œdema which, in the acute stage of poisoning, threatens the life of the subject, for if abundant it causes death by asphyxiation, the patient being in fact drowned by his own exudation.

The rate of onset and the degree of œdema are dependent on the particular gas and on its concentration, and, though in some cases to a less degree, on the duration of exposure. Of the acute lung irritant gases used during the war, phosgene, trichlormethyl-chloroformate, and chloropicrin may be regarded as the most lethal, and chlorine, chlormethyl-chloroformate, and phenyl-carbylamine-chloride the least, cyanogen bromide occupying an intermediate position.

As irritants of the upper respiratory passages there is a great difference between different members of the group. Enough pulmonary œdema to cause death may occur after poisoning with phosgene or trichlormethyl-chloroformate without any inflammatory change being visible to macroscopic or microscopic examination in the trachea or larger air passages, though the epithelium of the smaller bronchial tubes is definitely affected. On the other hand, chloropicrin always leads to marked inflammatory changes in the mucous membrane of the larger air passages—congestion, necrosis of epithelium, formation of inflammatory exudate—as well as to pulmonary œdema, and chlorine has an even more powerful action on the trachea and bronchial tubes. This difference in the pathological lesions appears to have a counterpart in a difference in the sensory irritation caused by the different gases, for coughing, tightness of the chest and actual pain are as a rule more pronounced with chlorine and chloropicrin than with the others. Chloropicrin is the most powerful lachrymator, yet even it ranks far below the true lachrymators, and chlorine is the least; phosgene, the chlormethyl-chloroformates, and phenyl-carbylamine-chloride exert a lachrymatory action which is by no means negligible in the field.

It has been pointed out already that after the initial group of cloud gas attacks, in which chlorine alone appears to have been used, it was a frequent and, in the later stages of the war, a practically invariable occurrence to find two or more gases figuring in any cloud gas attack or gas shell bombardment. It was consequently impossible on most occasions to say definitely whether the symptoms and pathological changes shown by any given casualty were attributable to a single lung irritant gas or represented the combined effect of a mixture of several different gases. To ascertain with precision the differences in the effects produced by the individual gases recourse had to be made to experiments on animals.

Morbid Anatomy.

In human cases submitted to autopsy in France the pathological changes found on different occasions differed rather in degree than in nature, and showed in general the following features.* When death occurred in the first twenty-four hours the lungs were voluminous and hardly collapsed at all on opening the thorax, but bulged forward so as partly to cover the area of pericardium normally left free. Distended lymphatics and small subpleural hæmorrhages were frequently visible on their surface, but it was only rarely that the latter coalesced and caused stripping of the pleura over any considerable area. Air which had escaped from the damaged lungs was often visible as chains of bubbles below the visceral pleura, along the interlobar fissures, occasionally penetrating the tissues of the mediastinum, and even escaping into the subcutaneous tissues to form a well-marked surgical emphysema at the base of the neck. The latter condition was of more frequent occurrence in the original series of cloud attacks with chlorine in April 1915, than at any subsequent date. The pleural cavity almost invariably contained a quantity of serous and sometimes blood-stained effusion, varying in amount from an ounce or two up to twenty ounces, though it is possible that much of this fluid had exuded from the œdematous lungs after death.

The lungs on removal from the thorax were heavy, being at least twice the normal weight ; in half a dozen typical cases the average weight of the right lung was 1,000 grm. and of the left lung 875 grm. On section of the lung the intensity of the pulmonary œdema and the vascular congestion were at once made evident by the frothy serous fluid and dark blood that dripped abundantly from the cut surface. Irregular alternating patches of collapse and acute emphysema extended throughout the lung substance. Occasionally definite infarcts were found in the lungs.

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* See the Official Memorandum by the D.G.M.S., and the works of Black, Glenny and McNee, and of Bradford and Elliott, referred to in the Bibliography.

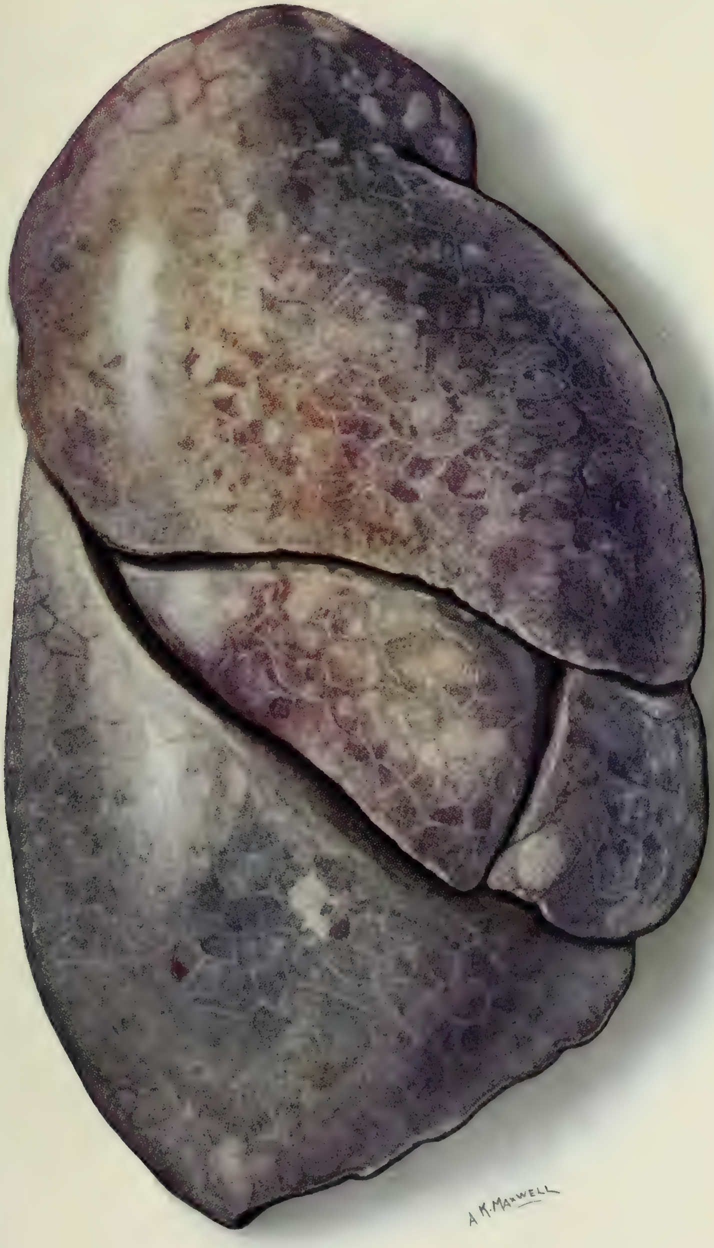
The trachea and bronchial tubes were largely filled with thin, yellowish, frothy and highly albuminous fluid, which was as a rule found escaping as a white froth from the nostrils and mouth after death. The degree of inflammatory change in the mucous membrane of the air passages was very variable. In the more marked instances, and particularly so with chlorine, the mucous membrane of the larynx, trachea and bronchi was intensely congested and of a deep purple colour, the epithelium swollen and the submucous tissue œdematous, though in no case was the œdema of the larynx in itself of sufficient intensity to endanger life. The epiglottis, too, was affected, but to a less degree than the trachea, while the mucous membrane of the pharynx was abnormally dry and glossy, and somewhat congested. In other cases the inflammatory changes were confined to the lower part of the trachea and the bronchi, the upper part of the trachea and the larynx being unaffected to the naked eye. Sometimes the whole of the larnyx, trachea, and larger bronchial tubes exhibited quite a normal appearance, save for their content of frothy fluid derived from the alveoli, and it is quite likely that these cases really represented the effects of poisoning by pure phosgene or trichlormethylchloroformate. Even when the inflammatory changes in the trachea and bronchial tubes were severe it was rare to find any evidence to the naked eye of false membrane formation.

The following details are quoted from the history of a case that died about two hours after the commencement of the cloud gas attack of 17th June, 1916, the gas employed being probably a mixture of chlorine and phosgene.

As the man was in the act of putting on his helmet, after hearing the gas alarm, a shell burst just behind him, more or less stunning him. So far as could be ascertained, he either did not get his helmet on properly, or at least received a very heavy dose of gas before he was able to do so. An hour later he was seen standing in a trench, when he was evidently badly affected, though he could still speak and answer questions. After being made to vomit by means of salt and water, he was carried back to the regimental aid post, where he died twenty minutes after arrival.

The *post-mortem* examination was made thirty-four hours later, after the body had been brought back for burial. The facies still showed an intense florid cyanosis. The lungs were not nearly so voluminous as was usually the case, yet the right lung weighed 1,150 grm. and the left 1,000 grm. They were uniformly bluish-red in colour, and showed on the surface neither

PLATE II.



Oedematous right lung from a casualty who died 6 hours after gassing by mixture of phosgene and chlorine, a cylinder of which was burst in the British trenches by enemy shell fire. The whole lung is congested and almost solid with œdema, while the interlobular lymphatics on the surface are distended with the same fluid. Here and there white islets of emphysema are visible.

petechial hæmorrhages, nor patches of acute emphysema, nor any evidence of air, save for a few bubbles at the lower edge of the lung. On section the whole of the lungs was solid with œdema, and only a few bubbles of air escaped from the bronchi on squeezing. The trachea and bronchi were intensely congested, the epithelium swollen, and the smaller bronchi filled by complete gelatinous casts, either of thick mucous or desquamated epithelium, which soon lost their form when handled after withdrawal from the bronchi.

When death occurred on the second or third day after exposure the general appearance of the respiratory organs was much the same, save that the aeration of the lung was distinctly greater than on the first day, and serous fluid did not drip so freely from its cut surface. The aerated condition was greatest in the lower lobes of the lungs where they were in contact with the diaphragm, the œdema persisting longest in the upper lobe. On the fourth day serous fluid no longer dripped from the lung on section, but the occurrence of greyish patches of definite broncho-pneumonic consolidation and commencing pleurisy sometimes indicated that secondary bacterial infection had set in. The increasing aeration of the lungs gave the impression that the œdematous exudation was being reabsorbed from the second day onwards.

In the circulatory system the large veins were engorged with blood, and the heart, particularly the right side, was usually, though not invariably, distended, and sometimes petechial hæmorrhages were visible beneath the endocardium. The pericardial fluid was sometimes increased in amount.

Petechial hæmorrhages and a slight superficial ulceration were frequently visible in the stomach (Fig. 1), and there were rare instances in which extensive hæmorrhage into the cavity of the stomach was reported, though there was never any evidence of the formation of deep ulcers. Apart from this, however, there was little significant change in the viscera save for general venous engorgement, with enlargement or nutmeg appearance of the liver and enlargement and congestion of the kidneys.

In cases of early death, the brain, as observed by Mott, showed as a rule nothing beyond marked congestion of all the vessels both in the meninges and in the cerebral tissue, but in some cases where death occurred, after two or three days of persistent cyanosis and unconsciousness, innumerable tiny petechial hæmorrhages were scattered throughout the whole of the white matter. This hæmorrhagic speckling of the white matter was particularly frequent after phosgene poisoning. In a few instances large and fatal cerebral hæmorrhages occurred on the first or second day.

Microscopic examination substantiated the naked-eye changes and furnished additional and important details. The whole of the lung was found to be affected by the œdema, which was readily coagulated by fixatives and stained, though the distribution of the fluid was irregular. The œdematous fluid contained desquamated alveolar cells and sometimes extravasated blood-corpuscles, but little fibrin could be detected save a layer applied to the walls of the atria and adjacent parts of a lobule. In some areas the alveoli were completely filled with fluid, and the capillaries in their walls were greatly congested ; in others the amount of fluid was much less, and some alveoli appeared to be completely free from it, particularly in the emphysematous patches, where there was little congestion of the capillaries. The emphysematous areas were evidently due not only to hyper-distension of the alveoli, but also to actual tearing of the tissue, the ruptured ends of the alveolar walls being clearly visible. Necrotic changes in the epithelium of the smallest bronchial tubes and some desquamation of the cells were usually visible, but the extent to which changes were observed in the larger bronchial tubes and trachea varied just as did the naked-eye signs of inflammation in this situation (Fig. 2).

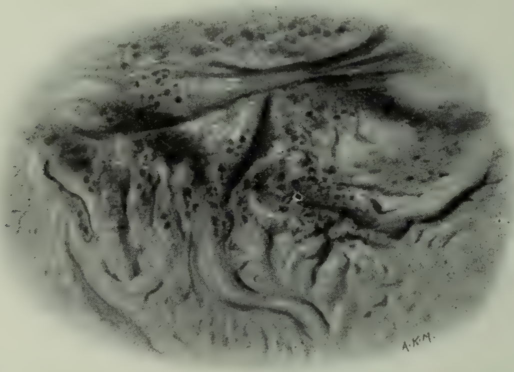


Fig. 1.—Inner surface of the stomach of a patient who died with diffuse broncho-pneumonia ten days after exposure to chlorine. Numerous petechiæ are seen and the stomach contents were mixed with blood, but there was no actual ulceration.

As a rule, patches of broncho-pneumonia could be identified in the lungs of the small proportion of gas casualties in France who succumbed from the third day onwards. Bronchopneumonia was perhaps more frequent after the cloud gas attacks of April 1915, when chlorine alone was used and the troops were unprotected. But those who ultimately survived exposure to the acute lung irritant gases did not often develop severe secondary symptoms of bronchiolitis or bronchopneumonia, even though they had been gravely affected by pulmonary œdema in the early stages. The striking feature in most of these cases was the speed with which serious

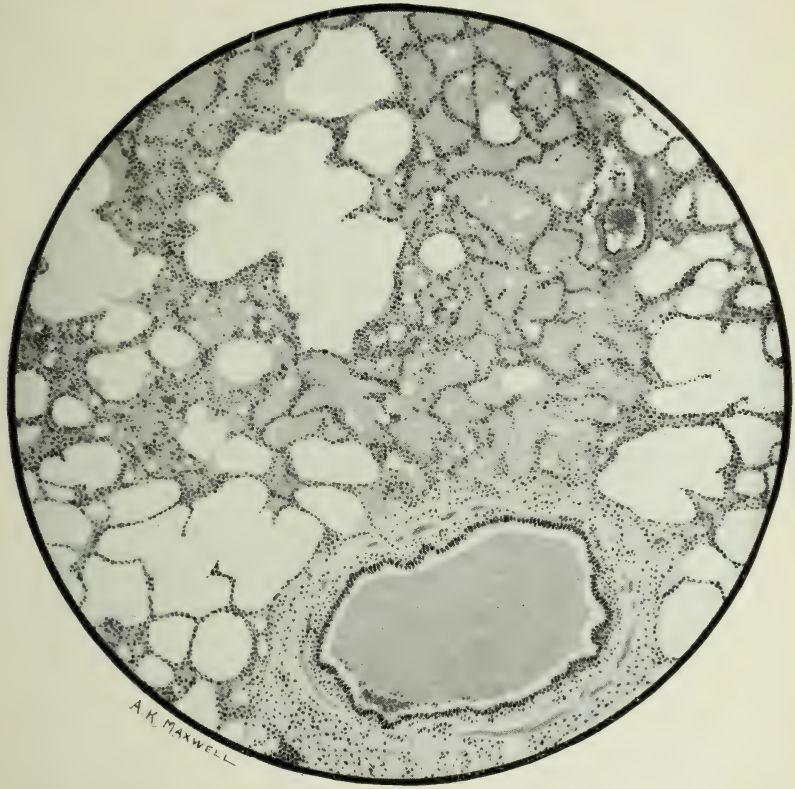


Fig. 2.—Microscopic section of human lung from phosgene shell poisoning. Death at the nineteenth hour after gassing. The piece of lung shown is almost entirely useless for aeration of the blood. Most of the pulmonary alveoli are filled with œdema fluid, and the walls of the air sacs are burst asunder in many places. The rounded edges of these torn walls can be recognized both in the areas of emphysema and in the parts that are flooded with œdema fluid. The bronchus also is filled with œdema fluid, but it should be noted that its lining epithelium is intact and pus cells have not accumulated in the secretion.

symptoms retrogressed when once the casualty had pulled through the acute asphyxial condition in the first forty-eight hours. The French mention cicatricial changes in the lungs in their official pamphlet on the medical aspects of gas poisoning, and the following quotation from the corresponding German pamphlet is of interest in this connection: "The precise significance of the bronchiolitis obliterans which is occasionally seen, and of similar changes (bronchiectasis, etc.) in the later stages of recovery from gas poisoning must be determined by future experience."

A new feature revealed by the microscope was the frequent occurrence of local thrombosis in the capillaries of the lungs. This tendency to capillary thrombosis was evident, too, in other parts of the body. Thus it was sometimes noticed in the kidneys, and may possibly have been responsible for degenerative changes occasionally detected in the glomeruli and tubules. The petechial hæmorrhages in the white matter of the brain were found to enclose a small area of necrotic brain tissue traversed by a capillary blood-vessel in which local thrombosis could be detected.

Experiments on Animals.

The main features of the pathological changes caused by the acute lung irritant gases are clear from the autopsies made on man, but the progressive development of these changes required to be followed out in detail in experiments on animals. Very clear accounts of the English observations on animals have been given by Edkins and Tweedy, and by Shaw Dunn in his reports on pathological changes and pulmonary lesions in goats, while the American investigations have been collected and copiously illustrated in a volume edited by Winternitz; extensive accounts of the German experimental work have also been published by Gildemeister and Heubner, Heizmann, and Laqueur. The following description is mainly taken from Dunn's work, but the other sources have been consulted.

The most valuable information is perhaps derived from those experiments in which the dose of gas was sufficient to produce serious illness without invariably causing death. Dunn, who worked with goats, found that an exposure to 1 part of phosgene in 4,000 to 5,000 for twenty or thirty minutes fulfilled these requirements, for about 60 per cent. of the animals succumbed to the pulmonary œdema.

As *phosgene* played so large a part in gas warfare it will be well to take first of all the effects produced by this gas. Within half an hour of the commencement of the exposure there is as a rule no alteration in the naked-eye appearance of the lungs, which collapse normally when the thorax is opened, but at the end of this time reddening of the centres of the lobules of the lung affords the first sign of commencing œdema. Very soon œdema develops in the interstitial tissues of the lungs and opens up the interlobular planes. On histological examination alveolar œdema is always recognizable at the end of half an hour, being indicated by the presence of light granular material mainly in the alveoli and in the cavity of the infundibula towards the centres of the lobules, and it occurs practically universally throughout the lung. Small numbers of desquamated alveolar cells, and sometimes red blood-corpuscles, may be seen in the alveolar exudate. The fibres of the interlobular planes, as well as of the peribronchial and periarterial connective tissue, are widely separated by fluid, and the lymphatic vessels in these situations are dilated. Edkins and Tweedy, who studied the effects of minimal lethal and sublethal doses of phosgene on rabbits, found that distension of the lymphatics with fluid, particularly the periarterial ones, preceded the appearance of actual liquid in the alveoli, and was a marked feature throughout the course of the illness, and they give good grounds for believing that the distension indicates a reabsorption of the œdema fluid through these channels, liquid only accumulating in the alveoli when the exudation from the capillaries can no longer be balanced by absorption. Lehmann, in his experimental investigation of the effects of chlorine and bromine, put forward a somewhat similar view.

Microscopical evidence of damage to the capillary blood-vessels is forthcoming at the end of half an hour, and becomes increasingly obvious in the next two or three hours. At first the capillaries in the walls of the alveoli nearest to the atrial opening of the bronchiole appear collapsed, containing many leucocytes but few blood-corpuscles, but soon minute thrombi appear in this situation. These gradually extend so as apparently to block the capillaries for some distance, though the thrombosis remains limited to the alveoli in the neighbourhood of the atrium. The capillaries on the fringe of this area are much engorged with blood, suggesting a condition of stasis, but the more peripheral capillaries have a more normal appearance

Occasionally the terminal portions of the bronchioles are irregularly constricted by contraction of the muscular fibres around them, and this may be sufficient to occlude the lumen.

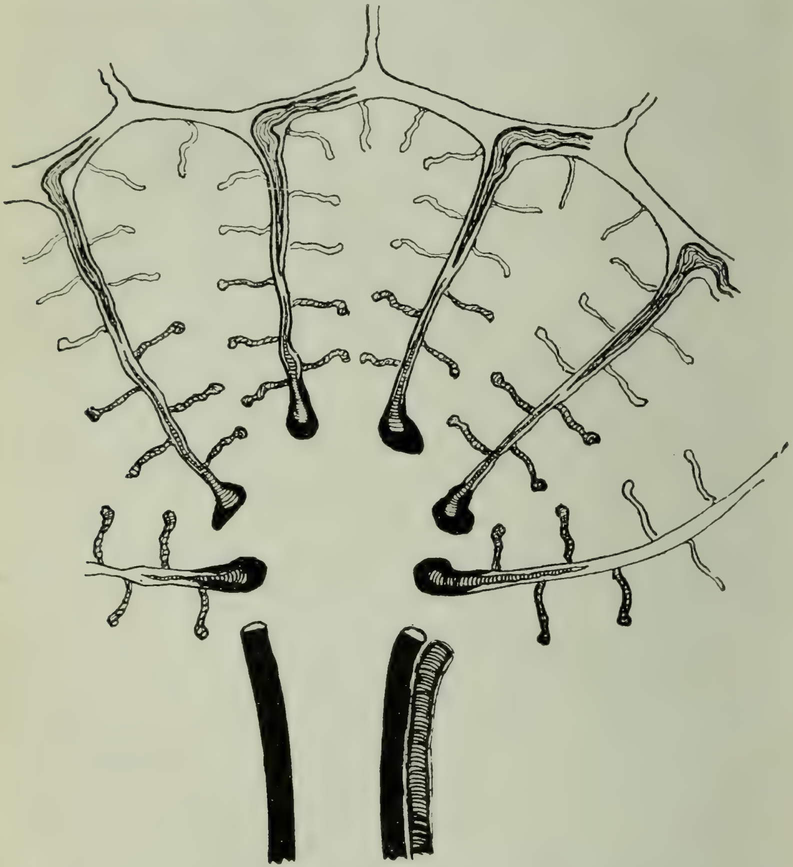


Fig. 3.—Diagram after Shaw Dunn of bronchiolar termination or atrium in lung of a goat, with infundibula opening off it. The dark masses on the ends of the partitions between adjacent infundibula represent muscular bands which may be regarded as belonging to the wall of the bronchiole and are liable to spasmodic contraction. The interalveolar partitions nearest to the infundibular openings are shaded to indicate the territory where capillary thrombosis may occur. Arterioles pass outwards between infundibula, and venules are formed peripherally.

The only noticeable change in the epithelium of the bronchial tubes at this stage is an alteration in the staining capacity of the superficial ciliated cells.

The œdema extends and becomes more intense during the next few hours, and is associated with progressive diminution in collapse of the lungs on opening the chest. Œdema is most pronounced in the ventral parts of the lung in animals, very probably from the influence of gravity and the greater difficulty of drainage of the lymphatics from this situation. Large areas of the lung may eventually become entirely filled with fluid to the exclusion of all air, and at this stage a certain amount of fluid is always found in the pleural cavities. By the end of forty-eight hours a differentiation into areas of solid œdematous lung and areas where œdema is slight or absent has, in the majority of cases, taken the place of the general diffuse œdema seen in the earlier stages. In the œdematous parts the fluid has become denser in consistency, and even if it does not completely fill the alveoli, it lies against the alveolar walls, hindering access of air to them. The cells of the alveolar epithelium become swollen if the œdema persists for more than twenty-four hours, and many of them are desquamated and are found in the œdema fluid together with a few polymorphonuclear leucocytes. In the less œdematous parts the alveoli may be dilated, though without actual rupture of the walls. In many cases the superficial ciliated cells lining the smaller bronchi and bronchioles are shed, but the lumen as a rule remains patent in those lobules that contain air unless spasm of the terminal bronchioles is also present, though the bronchioles leading to the solid lobules become blocked by albuminous material, mucous and epithelial debris.

The following table, taken from Dunn's paper, gives a good general indication of the degree of pulmonary œdema found at death in those goats in his series which succumbed after exposure to 1 part of phosgene in 4,000 to 5,000. The length of survival shown in this table should be compared with the length of survival of men who perished in the cloud gas attacks France (see Chart I, p. 395).

Day of Death.	1st day.	2nd day.	3rd day.	4th day.	5th day.
Number of deaths	54	30	12	6	1
Percentage of total deaths ·	52·5	29·1	11·6	5·8	1·0
Mean lung/heart ratio ..	8·15	8·70	6·55	4·84	4·80
Mean amount of pleural fluid in cubic centimetres.	160	150	90	—	—

The mean ratio $\frac{\text{weight of lungs}}{\text{weight of heart}}$ is in normal goats 1·5 to 3·0, and increase in this figure is in the main attributable to the accumulation of œdema fluid. The facts presented in this table agree closely with the conclusions drawn from autopsies in man as to the rate of accumulation and reabsorption of œdema fluid. In some of the animals which died in the first twenty-four hours the œdema, though universally distributed, was not of a high grade, and possibly these animals were of lower resistance than normal, or may have succumbed in part to shock.

The resolution of the œdema can be followed in those animals that survive the acute stage. The differentiation of the lung tissue into aerated and solid portions, which was observable at the end of forty-eight hours, becomes increasingly obvious. The rapidity with which the fluid disappears from the aerated parts is very largely determined by the facilitation of lymph flow under the influence of the respiratory movements, whereas the movement in the solid portions of the lung practically ceases. By the fourth day the dorsal parts of the lungs are more or less free from œdema and fully aerated, and even the solid areas have begun to shrink, this shrinkage being due in part to reabsorption and in part to the phagocytic action of macrophages derived from the alveolar epithelium. In the next few days the residue of the œdema gradually disappears from the alveoli, but aeration of these alveoli usually lags behind the disappearance of the œdema, and areas of collapse may persist for several days before re-expansion occurs.

The absorption of the capillary thrombi by phagocytes commences at the end of forty-eight hours and progresses gradually, the normal capillary circulation being apparently completely re-established in the end in the areas affected by the thrombosis. Some thickening and proliferation of the alveolar cells, particularly in the region where thrombosis occurred, remains visible for a time, while the bronchial epithelium is reconstituted from the basal cells. After a month or six weeks microscopical examination of even the ventral portion of a lung usually gives no indication that any lesion had ever been present.

With more severe doses of phosgene the general changes in the lungs are the same as with more moderate doses, but are more rapid in development and lead to earlier deaths. There is, however, a striking accentuation of the capillary thrombosis which affects a great portion of the lobules of the lung, and the alveolar capillaries are greatly engorged with blood, while minute hæmorrhages are present almost universally. In these cases there is evidence, therefore, of extensive damage to the pulmonary capillaries and of obstruction to the circulation. The American investigators point out that though the albuminous œdema fluid contains little fibrin, fibrin is deposited in greater quantity in and upon the alveolar walls, and they attribute interference with the capillary circulation rather to obstruction and compression by strands of fibrin in these situations than to actual intracapillary thrombosis.

Chloropicrin vapour causes much the same series of changes as phosgene so far as the alveoli are concerned, though the accumulation of œdema when it has once commenced seems to be more rapid. In contrast to phosgene, however, it causes serious damage to the bronchial tubes. Exposure to a concentration of 1 part of chloropicrin in 8,500 to 10,000 for twenty-five minutes was found by Dunn to cause a mortality of 77 per cent. in goats. In these experiments neither macroscopic nor microscopic examination of the lungs gave evidence of definite change immediately after the exposure. The commencement of œdema was visible an hour after the gassing, and by this time the bronchi were much congested and contained fragments of fibrinous clot, which were either loose or lightly adherent and scattered universally through the medium and larger tubes. At the end of two and a half hours œdema was very abundant, though the lungs also contained much air and remained fully distended on opening the thorax, the distention being partly due to hindrance to escape of air owing to the obstruction of the bronchial tubes by casts. The finest bronchioles and atria as a rule appeared little affected, the main damage being confined to the small and medium tubes. "The epithelial lining of these tubes is much damaged. The cells swell up and become dropsical, and their nuclei become pyknotic; massive desquamation takes place, leaving only a layer of basal cells *in situ*, or even these may be lost, exposing naked basement membrane. The lumina are occupied by the casts of loose coagulum in which desquamated epithelial cells are abundant. The vessels in the submucosa of the bronchi are greatly engorged with blood, and there may be some œdema of the connective tissue. This severe bronchial lesion, including the formation of obstructive casts, is separated by a space from the œdematous lesion in the alveoli and evidently arises independently of it." Associated with this blockage, or partial blockage, of bronchial tubes there is a greater tendency for the development of emphysematous changes in the lungs than in phosgene poisoning. In those animals that survived the acute stage of chloropicrin poisoning the general process of recovery followed the lines already detailed in the case of phosgene poisoning, repair of the bronchial epithelium was rapid, whilst no severe permanent damage of the bronchi was observed.

Chlorine affects the bronchial tubes to an even greater extent than chloropicrin, even the trachea showing signs of serious damage in severe cases, though the general features of the pulmonary œdema are the same as have been already described.

This inflammatory change in the larger air passages as a result of the action of chlorine or bromine was also recognized by Lehmann, who, after referring to the intense pulmonary œdema caused by exposure to relatively small concentration of the gases, states that when the concentration is greater "a thick, yellow-tinted typical croupous membrane of greater or less thickness is produced, which in the majority of cases stretches continuously from the larynx to the finer bronchi." Cyanogen bromide also has an inflammatory action on the mucous membrane of the bronchi, though the chlormethyl-chloroformates cause practically the same changes as phosgene.

In one respect the American observations made on dogs differ from those made in England on rabbits and goats, and that is in the liability of the dogs to develop a secondary bacterial infection of the lungs. Isolated patches of broncho-pneumonia might extend and coalesce to form considerable areas of broncho-pneumonic consolidation. Bronchiectasis and localized abscesses were sometimes found, while organization of the inflammatory exudate and necrotic tissue in and about the bronchial tubes often led to obliterating bronchiolitis. It seems likely that the actual course of recovery of casualties in France bore on the whole a closer resemblance to what was seen in the British rather than in the American experiments on animals.

It is clear from the accounts just given that the major damage caused by the acute lung irritants is confined to the respiratory system, and that lesions elsewhere in the body have no very distinctive character. At first sight the general tendency to capillary thrombosis and to the occurrence of petechial hæmorrhages, as well as the obvious signs of cardiac failure so often shown by severe casualties, suggest the possibility of a widespread action of the poison after absorption, but the facts are strongly opposed to this hypothesis. Intravenous injection of defibrinated blood or normal saline containing free chlorine produces no effect in animals. No ill-results follow the intravenous injection of serum or saline which has been shaken with phosgene, for this when brought into contact with water is almost instantly dissociated into carbonic acid and hydrochloric acid, and it is known that large quantities of acid can be injected intravenously without doing any material harm.* Even chloropicrin can be injected subcutaneously without producing any very obvious effects. Hill† has shown that the injection of extracts of the lungs of animals killed by chlorine or phosgene, or of their blood or œdema fluid, is harmless. This negatives the idea that toxic compounds may be directly produced in the lungs by the action of the acute lung irritant gases. He has further shown that if the gas is led to one lung only the damage is confined to that lung, the other lung remaining sound. Moreover, petechial hæmorrhages in the brain, precisely similar to those sometimes found in fatal cases of poisoning by the acute lung irritants, and even large cerebral hæmorrhages, are not infrequently found in fatal cases of carbon monoxide poisoning, according to Mott, where death is attributable to profound shortage of oxygen, though this lack of oxygen is caused in quite a different manner from that due to the acute lung irritant gases. Though nephritic changes have sometimes been noticed in the kidneys of both men and animals after exposure to the acute lung irritants, the weight of evidence is opposed to a direct action of the absorbed gas in these cases.‡ Everything, indeed, points to the fact that any pathological changes found in organs of the body other than the lungs are really attributable to changes resulting secondarily from the gross damage in the respiratory apparatus, and from the consequent asphyxia, and that the direct effects of the gas are limited to the lungs and bronchial tubes.

It has not infrequently been suggested that the toxic action of these halogen compounds ought really to be ascribed to the free halogen or halogen acid liberated by the dissociation of the compound on its entry into the cells. This may be true in part, and it is quite possible that the actual liberation of, say, hydrochloric acid *in situ* within the cells may be a more serious matter than the penetration of hydrochloric acid as such through the surface of the cell, but the great variation in toxicity and in irritant power of the different substances renders it difficult to accept this view in its entirety, and it would appear that the effect of the actual substances themselves must be reckoned with as well.

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* Chemical Warfare Medical Committee. Report No. 7.

† Chemical Warfare Medical Committee. Report No. 1.

‡ Compare reports by Dunn on experiments with goats.

General Physiological Results of the Lesions.

The outstanding changes in the lungs are the gross exudation of fluid into the alveoli, inflammatory and necrotic changes in the mucous membrane of the bronchial tubes, acute emphysema, and capillary thrombosis or obstruction of capillaries by strands of fibrin. The production of œdema is presumably due to the direct effect of the gas on the cells lining the alveoli and the epithelium of the subjacent capillaries, but whether this highly albuminous fluid is to be regarded as the product of an inflammatory reaction, or due merely to increased permeability of these cells, if not to actual gross leakage, is uncertain. The cause of the emphysematous changes is clear. As the œdema and other inflammatory changes develop, many of the bronchioles become obstructed by froth, fluid, or the swelling and disintegration of the bronchial mucous membrane, and perhaps to some extent by spasm of the muscle round the smallest tubes, while complete flooding of some of the alveoli with fluid must greatly hinder the entrance of air into them. The even expansion of the lungs is thus greatly interfered with. Those parts of the lungs into which air can still penetrate will become over-distended, if not actually torn, by the increased breathing movements. It is easy to see why actual disruptive emphysema should occur to a much greater extent in chlorine or chloropicrin poisoning than in phosgene poisoning. The inflammatory changes produced in the air tubes by chlorine and chloropicrin are severe, and the liability to blockage of these channels therefore great, while paroxysms of coughing, which imply violent respiratory movements, are a marked feature. Phosgene, on the other hand, causes far less sensory irritation and coughing, and has relatively little effect on the bronchial tubes.

These gross changes in the lungs are responsible for serious interference with the gaseous exchange between blood and air, and the indications of asphyxia were obvious in all severe cases of poisoning by the acute lung irritant gases. The cases fell into two categories ; the one was characterized by intense florid and deep cyanosis, with vascular congestion and engorgement of the veins, the other exhibited no venous engorgement but pallor akin to that seen in collapse, with grey or lilac-coloured lips and tongue. Both classes had the common feature that the colour of the blood indicated a grave deficiency of oxygen. These two types will be described more fully below, but if their significance is to be appreciated it is necessary to consider in detail the functional changes which must ensue from the damage in the lungs.

This aspect of the question has been dealt with by Haldane. When the gaseous exchange between the blood and the air in the lungs is hindered, effects on the body may be produced by interference both with absorption of oxygen and escape of carbon dioxide. Owing to the extreme sensitiveness of the respiratory centre to a rise of the tension of carbon dioxide in the blood, or more strictly to the slight increase in the hydrogen ion concentration caused by this, even a slight hindrance to the escape of carbon dioxide from the body is immediately followed by hyperpnœa (*i.e.*, an increase in the volume of air breathed per minute, not merely an increase in the frequency of breathing with proportional decrease in depth), which is maintained so long as the hydrogen ion concentration in the blood remains above normal. Sudden exposure of a person to air seriously deficient in oxygen causes, as a rule, immediate and great hyperpnœa, but this hyperpnœa at once reduces the carbon dioxide in the alveolar air in the lungs to an abnormally low level, and so causes carbon dioxide to escape at an excessive rate from the blood passing through the lungs. This process naturally leads to a gradual fall in the tension of carbon dioxide and of the hydrogen ion concentration in the body. The stimulus to the respiratory centre, therefore, decreases, for simple want of oxygen in the absence of a sufficient hydrogen ion concentration is a comparatively weak stimulus to the respiratory centre; the initial hyperpnœa soon moderates, being accompanied by an increase in the cyanosis, and eventually the breathing drops back to a steady level at which the ventilation of the lungs remains only slightly above the normal value. If serious deficiency of oxygen develops only slowly, the hyperpnœa is trifling and unnoticeable to the subject, and the most serious signs of want of oxygen—failure in the power of the limbs and loss of consciousness—may ensue without warning. Great and persistent increase of the breathing indicates that some other factor than simple oxygen want is present.

With regard to the conditions that obtain in the acute stage of poisoning by the lung irritant gases, Haldane makes the following remarks :—*

" In acute inflammatory conditions of the lungs there is sometimes want of oxygen, as shown by cyanosis, and where the inflammatory condition is accompanied by the presence of 'œdematous' exudation throughout the lungs the cyanosis is often very great. This condition is seen typically in the acute stages of poisoning by nitrous fumes or chlorine. What is the probable cause ? When a portion of the lungs, including even the greater part of both lungs, is entirely blocked by consolidation, as in croupous pneumonia, there is commonly no cyanosis. This indicates that very little blood is passing through the consolidated parts. What passes through the healthy portion is amply sufficient for respiratory requirements during rest. It must be borne in mind that the normal lungs and circulatory organs are adapted for meeting about ten times the respiratory requirements during rest, since the respiratory exchange is often about ten times as great during work as during rest. Hence, during rest in bed a very small proportion of normal lung will suffice for meeting respiratory and circulatory requirements, provided that there is but little circulation through parts which are useless. But when cyanosis due to a lung affection exists, in spite of the fact that air is entering the whole or a great part of the lungs freely, we seem driven to the conclusion that the entry of oxygen into the blood through the alveolar walls is impeded by exudation and increase in thickness of the alveolar walls.

" It is very important to realize that this may occur without any serious impediment to the passage of CO_2 outwards. CO_2 is about twenty-five times as soluble in water as oxygen, and hence it passes through the alveolar walls far more easily, with a given difference of partial pressure, than does oxygen. Moreover, a comparatively slight increase in the breathing will enormously increase the small difference in diffusion pressure on which the passage of CO_2 outwards depends ; but the same increase in breathing produces only a slight proportional increase in the diffusion pressure which drives oxygen inwards. Hence we may have cyanosis, and consequently very formidable effects from oxygen want, without marked hyperpnœa. The grey look of the patient's face will be a good indication of this. There will probably be no increase of venous blood-pressure with its accompanying full blue cyanosis.

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* *Brit. Med. Journ.*, 10th February, 1917.

"If great hyperpnœa accompanies the cyanosis there must be some other complicating condition. This accompaniment is seen typically in the acute stage of poisoning by chlorine or nitrous fumes; and the results of *post-mortem* examination, together with clinical observation during the recovery stage, seem to reveal the cause. In the acute stage the alveolar walls become extensively torn in efforts to breathe, despite the blocking of many of the bronchi by exudation or constriction. In consequence of this there is widespread emphysema, which is very evident on *post-mortem* examination. The areas round the emphysematous cavities are partially collapsed and very imperfectly ventilated, so that the CO_2 percentage rises in them to an abnormal extent. The emphysematous cavities are excessively ventilated, but this ventilation is of little use, since the proportion of sound alveolar wall to air is far too small. In consequence of this the CO_2 content of the arterial blood is raised, and hyperpnœa, along with increased arterial and venous blood-pressure, results."

According to Haldane the circulation was increased and the capillaries were distended with blood in the plum-coloured gas cases, because both saturation with oxygen was diminished, and saturation with carbonic acid increased in the blood of the capillaries. The distension of the superficial veins at the same time proved that the heart was failing to respond to the extra work thrown upon it, and failing on account of the imperfect oxygen supply as indicated by cyanosis. Not only the heart, but the respiratory centre also might rapidly fail in the same way and from the same cause, inadequacy of oxygen supply. The sign of a failing respiratory centre is undue frequency, as compared with depth, in the respiration. Rapid, shallow breathing, and a rapid, feeble pulse point alike to severe anoxæmia. If emphysematous changes are less pronounced and the diffusion outwards of carbon dioxide is not materially hindered in a case of acute pulmonary œdema, the effects will be those of a simple, uncomplicated anoxæmia. As the slight hyperpnœa reduces the concentration of carbon dioxide in the body, there will be very little increase in the circulation or in the distension of the capillaries with blood, and the heart will have but little work to do. The patient's face will therefore be ashen.

One can readily understand that if the oxygen supply to the body is interfered with by pulmonary œdema during rest, the attempt to perform muscular work may have disastrous consequences owing to the increase which is entailed in the oxygen consumption by the body in these circumstances. Collapse, and even death, often ensued with great rapidity when men who had been severely poisoned by phosgene attempted some muscular exertion, and Barcroft,* has recorded similar results in animals poisoned with phosgene.

It will be evident from the above that the precise functional effects caused by the interference with the gaseous exchange in cases of poisoning by the acute lung irritants will depend largely upon whether or not the shortage of oxygen is accompanied by damming back of carbon dioxide in the body, though it is in all cases the former which constitutes the real danger. No actual measurements of the content of gases in the arterial blood were ever made in a human case of gas poisoning. Haldane's theoretical explanation of the course of events is based mainly on the interposition of a thick layer of œdema fluid between the air in the lungs and the alveolar epithelium and upon what may be termed the structural disorganization in the lungs. There are, however, other pathological changes which require consideration, and it remains uncertain how much ought to be attributed to the somewhat indefinite factor of " shock."

Shock in the case of severe gunshot wounds has been attributed partly to nervous reflexes and partly to a direct action of toxic substances on the capillaries. Whatever the primary cause of shock may be, its features rest to a large extent on the stagnation of capillary flow, and the failure of the oxygen supply to the tissues resulting from this will in its turn depress the circulation and the functional activity of the nervous system still further. A vicious circle will in fact be established, and unless this can be broken at some point the patient must go from bad to worse. There was nothing to suggest " shock " in the ordinary clinical sense of the term in the aspect of those gas casualties who exhibited full blue cyanosis, but grey, collapsed sufferers from phosgene poisoning did appear to be in a position that might be ascribed to shock. This is not surprising. The moment serious circulatory failure began to result from the primary anoxæmia a vicious circle would be established similar to that suggested above, and one would expect the final picture to be much the same as in surgical shock.

It is not easy to assess the extent to which the pulmonary circulation may have been embarrassed by capillary thrombosis or pressure on the capillaries in the alveolar walls. Dunn's experiments with moderate doses of phosgene, which sufficed to kill a large proportion of the animals exposed, showed that the capillary thrombosis in these cases was localized in certain parts of the lobules of the lung, but neither the perfusion of coloured gelatine solution nor other methods afforded reliable evidence that the circulation was materially obstructed in the remainder of the alveolar capillaries. The rapidity with which cyanosis could be relieved and the heart's action improved by oxygen administration in the majority of human gas casualties, even though these might be of very severe type, suggested that the most serious factor in such cases was the hindrance to the passage of oxygen caused by the presence of œdema fluid, and showed in addition that there could be no material passage of venous blood through the non-aerated parts of the lung where the alveoli were completely filled with œdema fluid, a view which is in agreement with conclusions drawn by Barcroft from experiments on animals.* It seems probable, therefore, that in many cases capillary thrombosis played little or no part as an immediate cause of death. Dunn's experiments with more severe doses of phosgene indicated far more extensive damage to the capillaries, and there is good reason to think that in these circumstances circulatory obstruction in the lungs became a very real factor. It seems reasonable to assume, therefore, that the same factor must have played no inconsiderable part in the case of those gas casualties who succumbed rapidly on the field owing to exceptionally severe doses of gas.

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* *Journ. of R.A.M.C.*, 1921, Vol. xxxvi, p. 1.

The concentration of the blood which was so constant a feature in the acute stage is no doubt dependent on the loss of the fluid which constitutes the pulmonary œdema, on the condition of "shock," and on the anoxæmia. The relative increase in the number of red corpuscles implies an increase in the viscosity of the blood, and this will accentuate the strain on a heart already profoundly affected by deficiency of oxygen, the more so if there is any material obstruction of the bloodflow in the capillaries of the lungs, and will be a contributory cause to the right-sided dilatation and cardiac failure. Both American and German investigators have laid stress on the serious import of an increase of the viscosity of the blood in their experiments on animals.

It seems likely that the rapidity and relative shallowness of the breathing that characterized severe cases of poisoning by the acute lung irritant gases may have been determined largely by an accentuation of the normal reflex initiated by the passage of impulses up the afferent vagus fibres from the lungs, which cause inspiration to be converted into expiration and expiration in its turn into inspiration. It is certainly true that a single deep breath of air containing a considerable proportion of chlorine causes in man, after the immediate bout of coughing and choking has subsided, a marked increase in the rate and a reduction in the depth of the breathing, while any attempt to draw a deeper breath is attended by a sensation of discomfort in the chest and a tendency to cough, effects which may perhaps take half an hour to an hour to pass off. Direct inhalation of air containing chlorine into the lungs of animals causes a similar immediate alteration in the type of breathing, long before there is microscopical evidence of actual changes in the lungs, and it has been shown by Mayer, Magne and Plantefol, and by Laqueur and Magnus, the French and German investigators, that this characteristic alteration in the breathing does not occur if both vagi have been severed. Perhaps in such cases the irritant gas has made the vagal nerve-endings far more excitable to the normal stimulus caused by expansion and deflation of the lungs. Dunn has shown* that in experimental pulmonary embolism caused in animals by the intravenous injection of starch granules the breathing assumes a characteristically rapid and shallow form, and he gives clear evidence that in this case a change in the vagus reflex is the main factor concerned.

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* *Journ. of R.A.M.C.*, 1920, Vol. xxxiv, p. 155.

Deficiency of oxygen in itself tends to cause acceleration of the breathing rather than increase in depth, in contradistinction to the effects caused by excess of carbon dioxide when the hyperpnœa is mainly brought about by increase in the depth of the breathing, and should the breathing be shallow in spite of its rapidity the liability to shortage of oxygen will be increased, since shallow breathing is apt to lead to inefficient distribution of air through the lungs.† As will be shown subsequently, a shallow, rapid type of breathing occurred in some cases during convalescence from gas poisoning,‡ and here again there was reason to suggest an exaggeration of the normal vagus reflex.

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* *Quart. Journ. of Med.*, 1920, Vol. xiii, p. 129.

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‡ See Haldane's reports in the *Journ. of R.A.M.C.*, 1919, Vol. xxxiii; and Reports Nos. 5 and 11 of the Chemical Warfare Medical Committee, by Haldane, Priestley & Meakins.

CHAPTER XII.

THE ACUTE LUNG IRRITANT GASES. SYMPTOMS AND TREATMENT.

Chlorine Poisoning.

CHLORINE alone was used by the Germans in their first cloud attacks in April and May 1915. This gas is less toxic than other pulmonary irritants that were subsequently brought into military use, and therefore it is extremely unlikely that casualties from chlorine alone will ever again be experienced in warfare. But for historical reasons it is desirable that a brief account be given separately of the effects of this gas when used, as it was, in attacks upon troops unprotected by respirators.

A characteristic feature of chlorine poisoning is the immediate irritation of the sensory nerves of the respiratory passages. Exposure to the gas causes at once a choking sensation in the throat and such spasmodic gasping for breath that speech becomes impossible. Cough and, in some cases, vomiting follow quickly. Pulmonary œdema rapidly progresses, and the patient becomes cyanosed, while the cough is attended by profuse spitting of frothy fluid. Chlorine also causes some inflammatory irritation of the trachea and bronchi, and consequently exposure to it is often followed by the development of secondary infections and of bronchitis and bronchopneumonia. The leading symptoms observed were as follows :—

All the men gave a similar description of what they felt as the greenish-yellow fumes enveloped them. Immediate choking, coughing, gasping for breath and inability to speak proved the irritation and spasm of the respiratory tract. In many the eyes smarted and ran with water. Retching was at once experienced by some, but many did not vomit until an hour or two later. There was severe pain behind the sternum, which soon radiated outward on each side into the chest and added greater suffering to the distressed breathing. The throat burned and the dry mouth produced an intense sensation of thirst.

Very soon the developing pulmonary œdema led to the phenomena of oxygen shortage, with headache, a sense of weakness in the legs, and such lassitude that the men dropped prone upon the ground, the spasmodic violence of their respiratory efforts being then largely quietened. In this posture they lay in still greater danger, since the heavy gas clung in more poisonous concentration in the trench bottoms and recesses of the ground. Those who died on the field—and they were many—were described as being greenish-white in the face and not blue. No *post-mortem* examination of these early casualties on the field was made.

Milder cases, in areas where the concentration of chlorine in the air was relatively low, suffered chiefly from lassitude and a great sense of fatigue, which rendered them useless for fighting and equally incapable of taking precautions for their own protection from gunfire. This condition is illustrated by an account written immediately after the event by Lieutenant P.W. James, the medical officer attached to the 2nd Seaforth Highlanders. The battalion was holding trenches between St. Julien and Ypres, the German lines being from 600 to 800 yards away.

> " *Sunday, 2nd May* 1915 : About 5.0 p.m. word was passed round to stand to arms. In front of us appeared a fog-bank of rolling smoke 20 ft. high. Its base was greenish, and the top of a browner colour. The smoke came rapidly on to our trenches, where coughing and spluttering were at once heard on all sides, and the men began to break back in the attempt to escape from the stifling cloud. In fear of an imminent enemy attack, I endeavoured to get as many as possible back to the trenches. Here I was struck by the evident exhaustion of the men, who suffered from spasmodic attacks of coughing with an inclination to vomit. There was very little lachrymation or coryza. Some of them had worn pads wetted with water or bicarbonate of soda.
>
> " About 8.0 p.m. I had to give in myself and lie down on account of weakness. Cough did not trouble me much, but there was a good deal of watery secretion that came up without effort. I had lost appetite, but felt thirsty. Other men had headache, aching limbs, flatulence, and, in some cases, diarrhœa. All night in the trenches one heard groaning, not that of pain, but just the low muttering that is often heard in disease. On the afternoon of 3rd May I made my way along the trench line and found most of the men lying at the bottom. Two were cyanosed, but most were sleeping as from the effects of some poisonous drug. They seemed content to be left alone, and one did not hear the usual cry of ' Doctor.' As darkness fell, the battalion was reported incapable of further fighting, and I went sick myself."

This battalion was about 500 strong. Most of the casualties were mild. None died in the trenches, but at least four succumbed in the second or third day from pulmonary œdema.

A group of nearly 700 cases was admitted to No. 8 Casualty Clearing Station, Bailleul,* the majority six or eight hours after having been gassed in attacks during the second week of May 1915. " Most of the men were in a choking condition, making agonizing efforts to breathe, clutching at their throats and tearing open their clothes. At one moment they propped themselves up to gasp, at another they fell back exhausted by their struggle. The skin was cold. There was marked cyanosis, especially of the lips and ears, and in a few cases a light yellowish frothy discharge was escaping from the mouth and nose. Some, especially the older men, were in a state of collapse ; their faces and hands were of a leaden hue, their heads fallen forward on their chests. The majority of such cases did not rally. All, except those moribund or collapsed, were fully conscious and fighting desperately for life. Fourteen men died out of the first batch of seventeen taken off the motor ambulances."

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* See Black, Glenny & McNee : Bibliography.

It was noticed that the patients who lived tended to pass through three more or less definite stages while under observation at the casualty clearing station :—

(1) The asphyxial stage.
(2) The quiescent or intermediate stage.
(3) The bronchitic or broncho-pneumonic stage.

Nearly all the cases on admission were in the first or asphyxial stage. The vomiting and the extreme violence of the cough had now ceased. In the severest cases of asphyxia the congested face was of a purplish-red colour, the ears and finger-nails livid. The arteries and veins were distended, with a full pulse at a rate of less than 100 except in the collapsed cases, where it was thready and much more quick. The breathing was shallow and extraordinarily rapid, up to 40, 60, or even 80 in the minute ; but the movements were effected chiefly by the diaphragm and accessory muscles at the upper inlet, the chest itself being held in a position of utmost distension. Cough was frequent, but shallow and attended by pain. No abnormal odour was noticed in the breath. The percussion note was resonant except for a slight impairment over the bases behind, which later autopsy proved to be almost solid with œdema. The breath sounds were harsh, noisy, or feebler where œdema was spreading, and accompanied by numerous fine crepitant or mucous râles. In a few cases the air that escaped from scattered points, where the lungs had burst in emphysema between the areas of œdema, spread up from the mediastinum and ballooned out the neck and chest with subcutaneous emphysema.

In the first day there was a profuse expectoration of a yellow, highly albuminous fluid, which was sometimes so abundant that it ran from the patient's mouth when the stretcher was tilted head downwards. As much as 30 or 40 oz. of this was often expectorated in twenty-four hours. Later this profuse serous expectoration subsided, and was replaced by a viscous primrose-yellow sputum, which was often streaked with blood from tracheal hæmorrhages, or stained reddish-brown when it came from infarcted areas within the lung. Despite his hurried breathing, the sufferer complained more of pain in the throat, chest, and epigastrium than of shortness of breath ; and he preferred to sink down in the bed rather than to sustain the effort of sitting propped up. The lips were parched, the roof of the mouth glazed, and the tongue so heavily coated with a brown, dried fur that several patients repeatedly scratched the inside of the mouth with their finger-nails to remove the " leathery gluey feeling." The cold skin of the early stage of collapse soon gave way to a rise of temperature up to 100° or 101° ; but the skin was dry, unlike the general state of steaming perspiration which accompanies the occasional asphyxiation of ordinary bronchitis. While in this stage grave symptoms of circulatory collapse might appear with startling suddenness, but if patients could be brought safely through it, recovery was the rule. Roughly 25 per cent. of these serious cases died in the casualty clearing station, that is, within two days of having been gassed.

The first stage gradually passed off after about thirty-six hours, and the patient fell into a sleep from which he woke feeling much better. He continued in this state of comparative recovery for perhaps a day, and then symptoms of bronchitis began to manifest themselves. In the majority of cases these were not severe, but in a few broncho-pneumonia of a serious nature developed. The frothy serous expectoration was then replaced by thick greenish muco-purulent but inoffensive sputum ; consciousness often gave way to delirium ; the temperature rose rapidly to 104° or higher, and the pulse became of small volume and hurried, at a rate of perhaps 160. The œdematous râles persisted, and to these were added rhonchi in all the tubes and the breath-sounds of imperfectly consolidated lung, though not of definite lobar pneumonia. Many of these cases with secondary inflammatory complications died soon ; a few succumbed as late as the second week ; but practically all who survived into the third week recovered from their acute illness.

These complications were most frequent and more fatal in those gassed before the use of any form of respirator or pad, but the fatality even in these serious forms of broncho-pneumonia was less than 50 per cent., even at the very beginning ; and the results rapidly improved when medical arrangements were made in February 1916 to ensure that all cases with secondary complications should be detained for treatment at the casualty clearing station and not exposed to the disadvantages attending a railway journey to the base.

Subsequent History.—The after-effects of chlorine gas poisoning were not so serious as was at first apprehended from the extent of disruptive emphysema that had been revealed in *post-mortem* examinations of the lungs in cases of early fatality. Nor did other histological changes in the respiratory surfaces, that might have followed upon the severe inflammatory reactions, appear to have serious consequences in a later invalidism. A report by Meakins and Priestley in an article in the *Canadian Medical Association Journal* gives the most complete evidence that has been collected yet on this question. It rests upon a documentary analysis made four years later of the after-histories of 700 consecutive cases of chlorine poisoning taken from the records of field ambulances which received patients from the area north of Ypres held by the 1st Canadian Division in April and May 1915. In considering the analysis it should be borne in mind that efficient respirators were then unknown, that medical officers were entirely unfamiliar with the treatment of gas casualties, and, lastly, that Canadian soldiers with any apparent prospect of lengthy invalidism were very liable at the beginning of the war to be sent home to Canada for early replacement on the strength abroad by efficient substitutes. The second factor did lead most emphatically to an undue lengthening of the time of invalidism in England, and the third to an exaggeration of the proportion of those who were transferred to Canada as apparently permanent invalids.

Out of the total of 700 there were 368 who were either returned to duty from medical units in France or died in France. The remaining 332, or 47·4 per cent., were transferred to England, and these presumably serious cases provided the material of which the after-history was more closely investigated. The final records showed :—

Returned to France for duty	80 or 24·1	per cent.
Retained in United Kingdom for home duty..	48 or 14·5	,,
Invalided to Canada	204 or 61·4	,,

Of the 80 returned to France, 72 returned to full duty after one year, after being on an average two months in hospital, and ten months on home service. Of the 204 invalided to Canada, 16 were invalided for causes other than that of gas poisoning. The others were invalided after an average stay of nine months in the United Kingdom, four months being in hospital and five months on home service. These 188 cases out of the 204 were investigated four years after gassing, and their records showed the following conditions :—

No appreciable ailment	54
" Irritable heart "	78
Bronchitis and asthma	26
Neuroses	18
Not traced	12
	188

There was no evidence that any case transferred to Canada had died at a later date.

" Irritable heart " was the cause of prolonged invalidism in half of those cases that ultimately recovered for return to duty in France, in 70 per cent. of those retained for duty in the United Kingdom, and in rather more than half of those invalided to Canada. While this condition had vanished in a moderate proportion of these Canadian cases after the expiration of four years, it still appeared to have persisted in well above 10 per cent. of the 700 gassed cases, severe and light together. Bronchitis and associated pulmonary difficulties, apart from the dyspnœa classified under " irritable heart," were seen in quite a small proportion of all the three classes of cases, certainly in less than 5 per cent. of the total. Chronic gastric symptoms were extremely rare, and nephritis was never recorded. There were no cases of proved pulmonary tuberculosis, though several cases were noted to show a prolonged course with low fever, loss of weight, and profuse expectoration, similar to those described by Achard and Flandin as pseudo-tuberculosis after gas poisoning.

Investigations on a very much smaller scale were made by other officers of the after-histories, two years later, of certain particularly severe cases upon whom special notes had been taken while they were in base hospitals in Boulogne. Of these cases 40 per cent. had in that period of two years returned to full duty abroad. The following case of an officer illustrates the generally accepted observation that extreme subcutaneous emphysema from rupture of the lung does not of necessity indicate lasting damage to the lungs.

Patient aged 18. Gassed 1st May, 1915. Next day had subcutaneous emphysema of all upper part of body down to the loins. Some bronchitis for four weeks, but not severe pulmonary œdema. General muscular weakness and debility lasted for some time.

He returned to duty in 1916, and was killed on service in Mesopotamia, March 1917. After return to full duty he had no shortness of breath, nor any symptoms whatsoever of disability.

Another case showed the development of "irritable heart" after gas poisoning and infection, and the slow but complete recovery from that condition.

Patient aged 20. Gassed 24th May, 1915, in a heavy concentration, when the enemy trenches were only 80 yards away. Wore wet respirator, and stumbled his way 1½ miles back to medical post.

3rd day: At base hospital. Cyanosed and ill. Temperature 102° F., pulse 90, and respirations 40.

7th day: Still cyanosed. Purulent sputum and fever; fine râles both axillæ.

9th day: Imperfectly consolidated broncho-pneumonia.

16th day: Fever ended and convalescence begun. Sent to United Kingdom.

3rd month: No signs in lungs. Pulse 124 after very slight exercise. This tachycardia after effort persisted for a long time. Previously the patient was a fit man, having been in the regular army and seen two years' service.

16th month: Returned to France as fit for general service, and subsequently wounded in action.

It is needless to discuss in greater detail the after-effects of chlorine gas poisoning since the sequelæ were very similar to those of the other pulmonary irritants. Moreover, all the times of invalidism were unduly prolonged in these early casualties from chlorine, because the horror felt towards gas poisoning, when first used by the enemy as a means of warfare, was transmuted by medical officers, who were naturally ignorant of its possible remoter effects, into excessive sympathy for the patients.

Symptoms of Poisoning by Pulmonary Irritants in General.

For all practical purposes of medical treatment the lung irritant poisons that were used in the war may be classified in one main group. As chlorine was replaced by phosgene, and to the latter were added shells filled with chloropicrin or other compounds, any of which might be fired in combination in a gas attack, it became altogether impossible for medical officers to attempt more than a diagnosis as to whether a particular case of gas poisoning was caused by pulmonary irritants or by poisons of some other group.

It is true that casualties resulting separately from each of the known lung irritants in turn were at one time or another observed, but, as a matter of fact, these particular instances showed that there was little essential difference between the actions of the various substances. The treatment and the prognosis for all alike depended on the extent of the lesions produced in the lungs; and the extent of these lesions varied as much with the concentration of the gas to which the man had been exposed as with its particular nature, while they were to be determined by consideration of the clinical features shown by the casualty rather than by reference to the exact nature of the toxic substance.

The various poisons of this nature that were used in the war may again be referred to briefly. The immediate sensory reaction of the upper respiratory passages to chlorine is shown by violent coughing, spasmodic choking and gasping, and its irritant action on the lungs is exercised almost as rapidly. Casualties resulting from the action of other pulmonary irritants, that were used in 1916 and subsequently, showed much less cough and struggling distress ; the onset was slower and more insidious, but the result was often a far graver collapse of circulation in the asphyxiated men. Phosgene causes but slight sensory irritation, though this particular feature was not very noticeable, because phosgene was often employed by the enemy in mixture with other more irritant substances, such as chlorine or chloropicrin. Its inflammatory action is curiously restricted to the alveolar walls of the lungs, and there is some delay before even that action is established, but the pulmonary œdema produced by it is most intense.

An instance of this delayed action, taken from a fatal accident in England, deserves quotation because it illustrates clearly the strong contrast between the features of onset of pure phosgene poisoning and those of pure chlorine, as indeed they were actually experienced during the war.

3rd February 1917 : A chemist was working at a new chemical product. A syphon of phosgene, required for the synthesis of this substance, burst on his table at 1.0 p.m. A yellowish cloud was seen by a second person in the room to go up close to the chemist's face, who exclaimed, "I'm gassed," and both hurried out of the room. Outside, the patient sat down on a chair, looking pale and coughing slightly.

2.30 p.m. : In bed at hospital, to which he had been taken in a car, having been kept at rest since the accident. Hardly coughing at all ; pulse normal. No distress or anxiety and talking freely to friends for over an hour. During this time he was so well that the medical officer was not even asked to see the patient upon admission to hospital.

5.30 p.m. : Coughing, with frothy expectoration, commenced, and the patient was noticed to become bluish about the lips. His condition now rapidly deteriorated. Every fit of coughing brought up large quantities of clear, yellowish frothy fluid, of which about 80 oz. were expectorated in one and a half hours. His face became of a grey, ashen colour, never purple, though the pulse remained fairly strong. He died at 6.50 p.m. without any great struggle for breath. The symptoms of irritation were very slight at the onset ; there was then a delay of at least four hours, and the final development of serious œdema up to death took little more than an hour, though the patient was continually rested in bed.

Chlormethyl-chloroformate (the K-Stoff* of the Germans) and trichlormethyl-chloroformate or diphosgene (the surpalite of the French and K2-Stoff of the Germans) have a very similar action, with the same insidious delay in the development of pulmonary œdema. Chloropicrin, which was freely used in British as well as in German fillings, is a nitro-derivative (CCl_3NO_2) of chloroform, but it is intensely irritating to sensory nerves. It causes lachrymation, with sharp pain in the eyes, pain in the throat, and a considerable inflammation of the trachea similar to that produced by chlorine, while the pulmonary œdema resulting from it is greater than that from chlorine though less than that from phosgene. The general sensory irritation caused by a high concentration of chloropicrin may be so great as to make a man drop unconscious in a state of shock, though immediate death apparently does not result.

In the case of some of these lung irritant gases exposure even to a very low concentration in the air leads to a characteristic alteration in the taste of tobacco smoke, no matter whether the smoke is derived from cigars, cigarettes, or pipes. This effect is particularly marked in the case of phosgene and the peculiar taste of tobacco smoke may still be noticed many hours after reaching fresh air.

Casualties from poisoning by pulmonary irritants may be classified, according to their modes of onset, into three chief groups : —

(1) Acute, with violent onset.
(2) Acute, with insidious onset.
(3) Chronic.

Cases of chronic poisoning, from repeated or prolonged exposures to very low concentrations, were never experienced in military operations, but they were frequently observed among civilians in filling factories and they are of interest in helping to complete our knowledge of the toxicology of these substances.

Acute Cases with Violent Onset.—These are best exemplified in the cases seen after exposure to chlorine, and its early symptoms of coughing, choking and spasmodic gasping for breath caused by that poison have already been sufficiently described. Chloropicrin would produce an equally severe onset, but phosgene much less so. The question has been often discussed as to whether a man might be killed by immediate asphyxiation on the field through such a spasmodic closure of his larynx and bronchi that respiration was completely arrested. Sudden shock and collapse from extreme sensory irritation has been noted in animals immediately upon exposure to chloropicrin ; and it might be that this factor would also play its part in determining early death upon the field. But no proof was ever obtained that a man has thus been choked to death on the field. Owing to the difficulties of collecting reliable information during the excitement of a sudden exposure to high concentration of gas, when every man's immediate need was to get the protection of his respirator, it must be granted that the possibility of such a sudden death cannot be ruled out because it was not observed to have occurred. But if it ever did happen, it was of little practical importance. No medical officer in the trenches ever had the chance of attempting to treat such a case.

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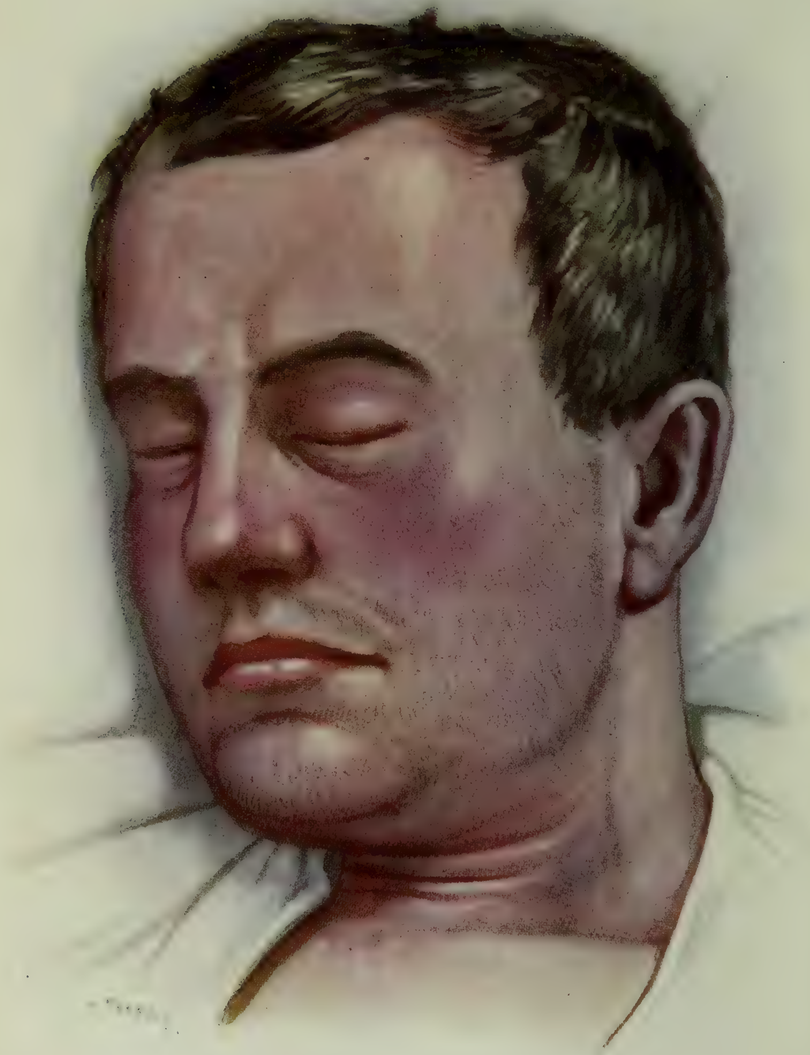
* Called *palite* by the French as an abbreviation of "municipalite," from the municipal laboratories of Paris that first provided the chemical analysis and formula of this substance when it was identified as a novel filling in unexploded German shells.

Very early deaths did certainly occur on the field, within the first or second hour after exposure and with such overwhelming rapidity in the progress of the fatal changes that the casualty had no chance of attempting to leave his ground for aid. A sinister example of this was seen in a cloud attack of 29th April, 1916, when the enemy used a mixture of chlorine and phosgene to which the PH-helmet then in general use was partly pervious. On this occasion about thirty men of the 8th Royal Inniskilling Fusiliers were found dead in their fire-bays at one stretch of the line, where the trenches were only 80 yards away from those of the enemy, and the group of men holding this point was practically annihilated.

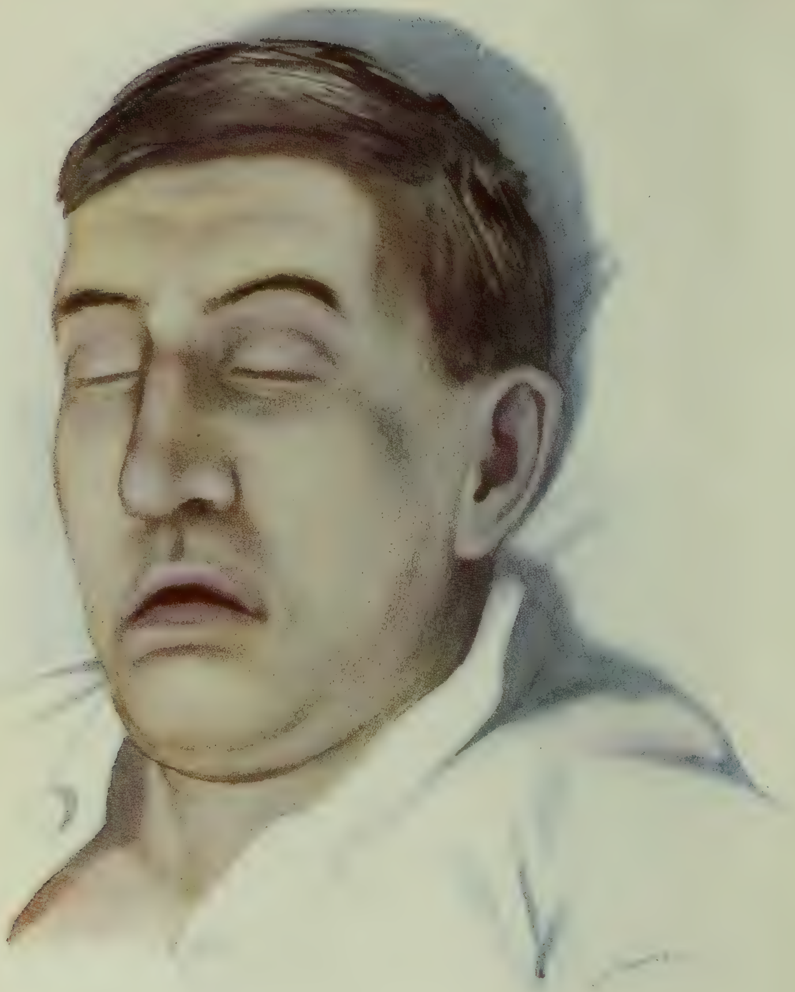
The earliest death in which a *post-mortem* was made was at about the end of the second hour after exposure, and in this instance both lungs were completely airless from pulmonary œdema. A rapid development of pulmonary œdema, interfering with gaseous respiration and also with the circulation itself, was probably always the actual cause of death. Usually death did not occur until after the lapse of several hours, so that, provided fighting conditions permitted movement, there was generally time for the evacuation of even the worst casualties to a medical aid post.

Soon after the initial coughing and perhaps retching had subsided, the patient felt a little pain in the chest, either behind the sternum or lower down in the epigastrium. A deep breath could not be taken, for the chest felt incapable of expansion and the effort increased the pain. Expectoration might be profuse, with foaming at the mouth, or very slight. Cough

PLATE III.



Blue type of asphyxia from phosgene poisoning with intense venous congestion. Drawing made early on second day after gassing, when there was copious frothy sputum, frequent cough, and hurried shallow respiration of 40 to 48, with temperature of 101° and full, strong pulse of 100. The patient was bled 15 ozs., and oxygen added to the air that he breathed. He soon made a complete recovery.



Pallid type of asphyxia from phosgene poisoning with circulatory failure. The cyanotic hue of the ears and lips, despite the general pallor caused by the failure of the circulation, indicates the intense want of oxygen from which the patient is suffering. Respiratory difficulty is shown in the strained effort of the muscles around the nostrils.
Drawing made on second day after gassing, when there was profuse frothy expectoration, hurried shallow breathing of 50 a minute, and a rapid running pulse of 132. The patient died two hours later.

was shallow, and sometimes quite infrequent. Vomiting was rare even in the severe cases. Headache and a great sense of fatigue in all the limbs often prostrated the man.

As œdema developed in the lungs, the breathing became rapid and panting, but of a characteristically shallow type, unlike the deep ventilation of a healthy man after running and more resembling the fast respiration of a child with bronchopneumonia. The ears, lips, and progressively the entire face assumed a cyanotic, bluish-red tint. In pure chlorine cases this deepened to the intense violet of fullest cyanosis. But in phosgene poisoning the stage of full venous congestion and deep cyanosis was often omitted, and the patient passed rapidly into a state of circulatory collapse, with a feeble, flickering pulse of over 120, a cold clammy skin, and a leaden hue in the face, in which only the lips and tips of the ears revealed the asphyxial cyanosis that underlay the failure of the man to win his fight for life. While in the stage of cyanosis whether " blue " or " grey," the patient was always restless and very apprehensive of the seriousness of his condition. The expression was anxious and distressed, with the eyeballs staring and the lids half closed.

At this stage casualties could be divided into three types :—

(*a*) The milder case, with a reddish flush in the face, with some hurry of respiration, and with pain in the chest and epigastrium which was increased by coughing.

(*b*) The severe case with " blue " cyanosed face, distended neck veins, and full strong pulse of 100. (Plate III.)

(*c*) The severely collapsed case, with leaden " grey " cyanosis of the face, and rapid thready pulse. (Plate IV.)

The milder case was often drowsy, and soon fell into a sleep from which he awoke refreshed. Coughing upon a deep breath, occasional vomiting after food or drink, and a slight sense of rawness in the throat, together with general debility, might persist for a few days ; and the patient was then convalescent. During the early days of convalescence there was often a considerable slowing of the pulse from vagus action, which might bring it down to about 50 or even 45 in the minute. Such early bradycardia was often seen too in recovery from severer poisoning. It had no serious import.

Cases of severer cyanosis, if the depth of the reddish-blue colour was well maintained and the pulse did not exceed 100, tended to recover in two or three days, and their recovery then was generally similar to that of the milder cases. Provided that the circulation could be maintained, the œdematous fluid in the lungs was soon absorbed and most of it had vanished by the end of the fourth or fifth day. But at any time, and particularly if subjected to much physical effort, these men might rapidly pass into the most dangerous condition of grey cyanosis and collapse. The pulse became rapid, thready, and sometimes irregular. The patient, though obviously weaker, became more restless and slightly wandering in mind or semi-comatose.

A group of such asphyxiated cases, some purple and some collapsed and grey, was described in a report by Captains Glenny and Kaye from No. 8 Casualty Clearing Station, Bailleul. An enemy cloud gas attack of phosgene mixed with chlorine had been made on the Wulverghem front soon after midnight on 30th April, 1916. This casualty clearing station received 321 casualties; 41 of them were gravely asphyxiated and 30 died within two days. These grave cases included "some moribund men who were lying unconscious, with frothy secretion escaping from nose and mouth. The leaden blue colour and laboured and rapid respiration were very striking and pitiable. They were cold and clammy, and in the last stages their pulses were feeble and flickering. Others in a less advanced state were extremely restless, throwing themselves about and calling out. They presented a picture of the utmost distress as they felt suffocated by their own secretions and unable to breathe despite their violent efforts. Frequently they would attempt to make themselves vomit or expectorate. One man who was in the greatest distress suddenly lost his reason and ended the struggle by cutting his throat."

Even the worst of the grey cases might recover with proper treatment; but the mortality among them was always distressingly high. Recovery from this state of depressed circulation might be succeeded by severe and even fatal broncho-pneumonia. When this infective complication developed the sputum became purulent and the temperature rose above 102° F. to any height. Death usually came soon with this secondary infection. If a case lasted into the third week after gassing, he might justly be expected to survive the acute infection. The long delayed deaths after recurrent broncho-pneumonia with slow gangrene of the lung or empyemata that were so often seen with mustard gas were relatively rare after infection following upon exposure to pulmonary irritants, because the latter, and phosgene in particular, did not cause a serious necrosis of the membranes lining the respiratory passages. Laryngitis was also unusual.

The diagram, Chart I, by Douglas, shows in comparative curves the times when death occurred in cases of poisoning by phosgene and chlorine mixed and by mustard gas respectively.* It will be seen that 81 per cent. of the total 424 deaths from phosgene and chlorine occurred within twenty-four hours after exposure to gas, and that after the fourth day the mortality had almost ended. These 424 comprised the total deaths, either in the trenches or in medical units, from the cloud gas attacks of the three dates mentioned. The times of death in these gas casualties correspond very closely with the survival times found experimentally in goats gassed with phosgene and enumerated in the Table on p. 371 of the preceding chapter.

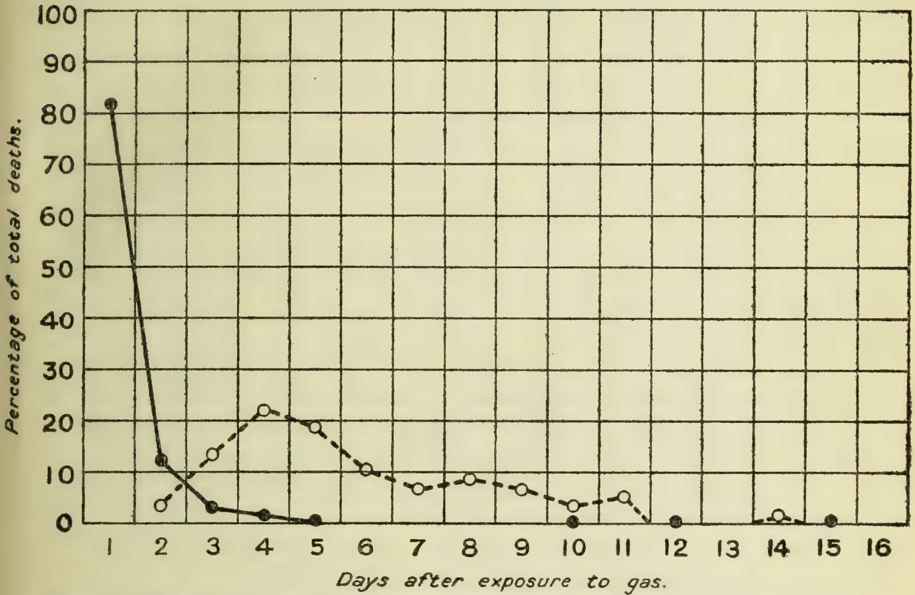


CHART I.—Curves showing times of occurrence of death in cases of gas poisoning.
———————— = deaths from chlorine and phosgene.
- - - - - - - - = deaths from mustard gas.

On the other hand, the curve of deaths from mustard gas is at its maximum on the fourth or fifth day and it is long drawn out. The 59 fatal cases upon which this curve is based were the total deaths from a particular instance in which, owing to neglect of anti-gas precautions, three siege batteries suffered very severely and the casualties were of a peculiarly severe type, with nearly 50 per cent. of deaths among them.* It is probable that in this instance the deaths may have bulked more heavily than usual in the earlier days on account of the severity of the poisoning.

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* *Jl. of R.A.M.C.*, 1920, Vol. xxxv, p. 79.

Physical signs in the chest were of little value in estimating the gravity of the case and the extent of the pulmonary œdema. In the milder cases fine râles might be heard on deep inspiration, chiefly in the axillæ and behind. Serious cases were judged by the pulse, the rate and character of the respiration, the colour, and by the mental condition. No further information of value was gained by physical examination of the chest. The main signs in the graver cases of œdema have already been described. Subcutaneous emphysema was rarely seen after any pulmonary irritant gas other than chlorine.

Pulmonary œdema obstructed the gaseous exchanges of respiration, and this was the main cause of the failure of the circulation through its interference with the oxygenation of the heart, and also with the tone of the capillaries. In addition, the blood-flow was partly impeded by three subsidiary factors that were proved to exist:—

(1) By the pressure exerted on the pulmonary capillaries from œdema fluid accumulated in the lungs and from inflammatory fibrin deposited within the alveolar walls.

(2) By scattered intravascular thrombosis within capillaries of the lungs or even in larger vessels.

(3) By the increased viscosity and concentration of the blood itself, caused by the withdrawal from it of so much œdema fluid. The coagulability of the blood was a little increased, though experiments on animals did not lend support to this clinical observation. Its concentration in severe cases was shown by blood-counts as high as 8·5 million reds per cubic millimetre (from the blood in large veins, and not from the arteries); this would imply considerable reduction in the blood volume, but no direct measurements of the change were made. The concentration is illustrated in the following case that was reported in a group of similar observations by Captains McNee and Shaw Dunn. The Haldane hæmoglobinometer used by them had given a reading of 90 for the hæmoglobin percentage of normal soldiers during trench life.

Pioneer of Special Company, R.E. Gassed at 9.0 p.m. on 2nd June, 1917, on the eve of the Messines attack, as a result of one of our own gas cylinders—phosgene and chlorine—being burst by a shell; he took some time to get on his respirator.

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* See detailed account on p. 314, and Table XVII, Chapter X.

3rd June: Admitted to No. 54 Casualty Clearing Station in the morning. Much cyanosed and dyspnœic, with a good deal of cough and fairly abundant expectoration. Not collapsed. Oxygen given by nasal tube. At 3.0 p.m.: Pulse 108 to 120. Respiration 30 to 48. Hæmoglobin 120 per cent.; red corpuscles 8,190,000.

4th June: Some improvement. Pulse 110. Respiration 30 to 50. Hæmoglobin 108 per cent.; red corpuscles 7,480,000.

5th June: Pulse 90. Respiration 32 to 56. Hæmoglobin 90 per cent.; red corpuscles 6,000,000.

6th June: Much improved. Pulse 80 to 90. Respiration 28 to 40. Hæmoglobin 82 per cent.; red corpuscles 5,320,000.

This patient recovered rapidly and was soon evacuated to England, where he was passed for duty in November, but did not return to France. In November 1920 he was receiving a pension of 20 per cent. for neurasthenia of a melancholic type, but he showed no features of disordered action of the heart.

A concentration up to 120 per cent. with 8,000,000 red cells was in another instance seen within seven hours of gassing; in fatal cases it was observed to rise to 135 per cent. with nearly 9,000,000 reds before death. In milder cases there was no such concentration of the peripheral blood. It should be remarked that these blood-counts were made from the small superficial vessels after pricking the ear, and not from the deeper venous channels. Work on the circulation in wound shock done at a later date in the war proved that shock is accompanied by a stagnation of blood in the superficial capillaries and by exudation of serum, so that the blood-count is higher in blood from the ear than in blood from deeper veins. "Shock" may have existed in gassed men, and added to the difficulties of the circulation. The blood-counts quoted above cannot be taken as a true measurement of the concentration of the main mass of the circulating blood, but only as approximate indications. But complete experimental observations on gassed animals * showed a true concentration of nearly 30 per cent. of the original volume, with a count in the circulating blood rising to nearly 7,000,000 reds. As in the human case quoted, the blood figures in animals fell to normal in three or four days with disappearance of the pulmonary œdema.

During acute poisoning there was no actual change in the cellular elements of the blood, and the blood constituents showed no change in respect of their efficiency for the transport of oxygen and carbon dioxide, except in so far as there might be some depression of the alkali reserve. Measurements of the gaseous contents of the arterial blood were not made, but it is most probable from observations in civil life on the oxygen content of arterial blood in cases of deep cyanosis during

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* Report by Dufton, No. 4 of Chemical Warfare Medical Committee.

ordinary pneumonia, and also from experimental work on gassed goats, that the oxygen content was reduced by nearly a third of its proper saturation. The slowness of the blood-flow through the tissues in severely gassed goats was shown by the observation that the venous blood was found to be almost completely void of oxygen at a time when the hæmoglobin in the arterial blood was still 70 per cent. saturated with oxygen (normal 98 per cent.). A thick viscous blood, with an inadequate charge of oxygen, was therefore circulating very slowly through the vessels of gassed patients. All the tissues suffered severely from "oxygen want." Their saturation with retained carbon dioxide and other metabolites was perhaps of a less serious nature.

Measurements of the blood-pressure were not made in the British service, but French observers agreed that the systolic arterial pressure tended always to be subnormal and the diastolic high. This inefficiency of the circulation might at any moment be aggravated by rapid failure of the heart, presumably from oxygen want in the labouring cardiac muscle. Such cases of early collapse, " cardiac " as they were often termed, were rare with chlorine, but so common with phosgene that at first they were hardly recognized as being of an asphyxial nature, and their cause was ascribed by many medical officers to a direct toxic action of phosgene on the heart and circulation. Clinicians were always unwilling to abandon this view, but the balance of evidence from pathological and experimental observations is against its acceptance, and for the present it is thought that the entire action of pulmonary irritants is exercised solely upon the surface layers of the body with which the gases come into immediate contact, the early circulatory failure being caused only by the influence of pulmonary œdema upon gaseous respiration and blood-flow and by " shock."

Intravascular thrombosis occurred chiefly in the capillaries around the atria and termination of the bronchioles, where the fullest action of the poisonous irritant is exerted directly upon the vessel walls. *Ante-mortem* clotting in the heart-chambers was rare, and embolic phenomena were unknown. But thrombosis secondary to the altered state of the blood was also seen outside of the lungs. The glomerular vessels of the kidney, the small terminal arterioles of the brain, the splenic vessels, might all display microscopic thrombosis. Rarely even larger vessels, arteries as well as veins, might suffer slow occlusion, and such a condition has been observed to lead to gangrene of a leg, requiring amputation, while one case was reported of death from slowly progressive thrombosis of a chief pulmonary artery.

The stomach in severe chlorine cases often showed abundant petechial hæmorrhages, and was sometimes full of blood after death. These changes were much slighter with other pulmonary irritants. No authentic case of gastric or duodenal ulceration was ever discovered. The vomiting of onset, which was partly reflex in origin, soon passed away, and digestion was normal again in a short time. Initial diarrhœa was infrequent, and probably nervous in nature. The bowels showed no subsequent abnormality beyond that of occasional constipation. Albuminuria was rare, and nephritis was never proved to have developed as the result of gassing either early or late in the history of the case.

Nervous symptoms, apart from the restlessness or semi-coma associated with general fault of the circulation, were rare. The mental changes that characterized carbon monoxide poisoning were never seen ; peripheral neuritis did not occur except as the result of direct postural pressure on a nerve during coma, and there was no loss of smell or taste. Occasionally in severe asphyxia a large cerebral hæmorrhage was proved to be responsible for hemiplegia and convulsive fits. The abundant petechial hæmorrhages found in the white substance of the brain of fatal phosgene cases that had lived in a state of comatose asphyxia for a day or two may not have been present in those who survived. At any rate, serious cases with severe and prolonged asphyxia usually recovered with a perfectly normal mentality, and there were but few who displayed intractable neurasthenic phenomena.

Acute Cases with Insidious Onset.—When the tension of a gas attack had passed away, it sometimes happened that, among those who had been exposed to the irritant vapour but had not reported sick, a man would stop working, complain that he felt done in, and die in a few minutes. Others might survive for an hour or two after a similarly sudden collapse. Their deaths were at first thought to have been caused by heart failure due to a direct intoxication by the gas. Autopsies, though not made in the dramatic cases of abrupt death, always proved the existence of advanced pulmonary œdema, the condition being really identical with that of "grey" collapse as seen after the ordinary acute onset.

Pulmonary œdema may set in hours after exposure to phosgene, just as it does with nitrous fumes. The condition may be slight at first, and apparently then be aggravated in some unexplained way by physical effort; or it may be that the œdema is always considerable but unattended by any manifest symptoms until muscular work demands more oxygen than can be supplied by the damaged lungs, and the exhausted heart suddenly fails. It was even stated that the eating of an ordinary large meal might, perhaps by pressure upwards through the diaphragm, be an immediate cause of such a sudden development of grave features in a previously mild case. At any rate, as the following incident shows, casualties might feel relatively so well and have suffered so little in the first onset of poisoning as to be able to eat freely, and then die a very short time afterwards. Very similar events have been reported in cases of poisoning by nitrous fumes.

> "5th June, 1917: During the night, two companies of the Seaforth Highlanders were employed in shovel and pick work for the consolidation of trenches. At 3.0 a.m. they were, while digging, suddenly subjected to an accurate fire of enemy gas bombs, probably phosgene, from light trench mortars.
>
> The men marched back some distance, only three having complained of feeling ill. About 5.0 a.m. they had breakfast, and after the meal a number of men vomited and complained of difficulty in breathing. Several men, after a short sleep, woke up with similar symptoms. One sergeant died soon after breakfast, and another who was taking the names of the sick men suddenly collapsed and died. There were 91 casualties, of whom 18 ultimately died."

These casualties were probably caused by pure phosgene, and their slight initial features with rapid and fatal development after a delay of three or four hours were in close parallel with those of the chemist in England quoted on p. 390. Delay in the features of poisoning would naturally be less evident when phosgene was mingled, as it usually was in the war, with other substances, such as chlorine or chloropicrin, that caused severe sensory reaction at the very onset. Delayed cases of gas poisoning, as seen in France, tended to appear in three forms:—

(1) In sudden death during the first day, without premonitory symptoms. These were very rare.

(2) In a rapid development during the first day of the ordinary features of pulmonary œdema, even in its most dangerous form. For example, after a gas attack at 12.20 a.m. on 9th August, 1916, an officer went round his dugouts at 7 a.m. and was apparently quite well. He was taken ill shortly afterwards and died of pulmonary œdema in one and a half hours.

(3) In a milder form, when men reported sick three or four days after the attack, with vomiting, abdominal pain, shortness of breath, and fatigue. The temperature was often raised a degree or two. They might show cardiac distress and tachycardia, but they never passed into a dangerous state.

Such delayed cases were not uncommon at first, but they became rarer when officers realized the danger of allowing mild casualties to undertake heavy effort, and insisted that all men with any features of pulmonary irritant poisoning should be rested for twenty-four hours.

Chronic Cases.—Workers in phosgene or chloropicrin factories were occasionally exposed to low concentrations of escaping gas. With repeated exposure they became more susceptible to its poisonous effects, and ultimately reported sick either with general debility, shortness of breath and a rapid pulse after exercise, or with recurrent attacks of asthma.

The asthma was often prolonged for a day or two in older patients who were already subject to emphysema and chronic bronchitis. In others the attacks were spasmodic, and occurred more often at night, though sometimes induced during the day by physical exertion. The pulse and respiration were accelerated in the attacks ; there were cyanosis and often violent coughing with tenacious expectoration. Pulmonary œdema was never reported as the result of chronic poisoning. The asthmatic attacks indicated chronic irritation of the respiratory passages. The debility and tachycardia were usually regarded as a secondary result of hindered respiratory exchanges, and not as being caused by a slow intoxication after absorption of the poisonous vapours.

Sequelæ of Poisoning by Pulmonary Irritants.

When the pathological character of the lesions produced was first realized, the ultimate history of survivors from gas poisoning was very problematical. It was thought that a large number would be hopelessly disabled by chronic emphysema. The development of tuberculosis was anticipated. American workers in laboratories prophesied that a liability to pulmonary hæmorrhage after muscular effort might follow the lesions caused by pulmonary irritants, and that the skin burns from yperite would be followed by the development of cancer. None of these dark predictions have yet been justified. The ultimate sequelæ were much less grave, and they were found, by the only true method of following up the after-history of a number of casualties, to be of a different nature from what had been anticipated. Bronchitis and emphysema were relatively rare ; tubercle extremely so. Gastric symptoms, pain or poor appetite, were occasionally reported, but the commonest feature was a prolonged inability for severe muscular effort or even for moderate exercise, and this was associated with tachycardia and a rapid, shallow type of breathing.

The men's "wind" was gone, and to some extent their "nerves" with it. They showed giddiness on standing, headaches, and general vascular instability. The condition lasted for many months and often proved most difficult of treatment. It was closely allied to the condition of disordered action of the heart. The questions arose successively as to whether it was due to damage of the heart itself, or to such lung injury that there was persistent oxygen shortage in the body, or to a neurasthenia with nervous disturbance of the normal type of breathing so that oxygen shortage again was produced and the circulatory muscles in consequence worked at a disadvantage.

The earliest reports from England and from convalescent depôts in France spoke only of general debility, gastric disturbances, and shortness of wind as the features of prolonged invalidism after gas poisoning. In June 1916, Captain Riddell, of No. 1 Convalescent Depôt, Boulogne, reported that some features of heart trouble had developed in a number of men from the April attacks, phosgene and chlorine mixed, when they had been put early to light work in the depôt and had had no opportunity for resting during the day. There were pallor and giddiness on standing, together with a fall of blood-pressure to 90, while the pulse might rise to 140 or more. The large arteries in the neck showed very visible pulsation, and loud systolic murmurs were heard over the cardiac area when the patient was recumbent.

Arrangements were at once made for fuller study of the condition, and a batch of nineteen such men, who had been moderately gassed and then developed tachycardia during early convalescence, were sent over to the special Military Heart Hospital in London. Dr. Thomas Lewis reported that there was no organic fault of the heart, nor any dilatation revealed by the orthodiagraph, and that the condition was closely akin to that of disordered action of the heart in a mild form, with fair recovery upon carefully graduated physical exercises.

The investigation was continued in France, and from the next cloud gas attack of 8th August, 1916, which was of a very severe nature with 46 per cent. of deaths on the total casualties incurred, 220 cases of intermediate severity were sent for study of their later symptoms and times of recovery to a special rest station at No. 25 General Hospital, Hardelot. The cases were detained there up to the sixth week, and their later progress, if not evacuated to England, watched at the neighbouring convalescent depôt. The following features were described by Captains Hunt and Price Jones :—

Pain in the head, generally frontal, was common. It was often worse after exercise. Pain in the epigastrium, often worse after food, was frequently a complaint. It was rarely severe and soon vanished altogether. In only 1 per cent. was there persistent dyspeptic trouble. Pain in the chest, either right across or precordial, and sometimes associated with cutaneous hyperæthesia, was variable. It was most frequently complained of after exercise. Mild bronchitis was present in about 15 per cent. of all cases. A slight evening rise of temperature was noticed in many cases, altogether apart from bronchial catarrh. None showed clinical evidence of emphysema developing.

Disordered action of the heart or irritable heart in its typical form, with precordial pain, exhaustion, dyspnœa, and persistent tachycardia after exercise, was found in one-third of the total. Spasmodic attacks of nocturnal " asthma," either alone or in association with the features of disordered action of the heart, occurred in less than another third. The attacks, which recurred at varying intervals, might last from three to thirty minutes. The patient was rarely cyanosed, and he looked anxious rather than ill. The respiration was shallow and rapid, but not difficult, and there were no abnormal physical signs in the chest during the attack. The pulse might be slow and full, or rapid and almost impalpable. In uncomplicated cases, unassociated with disordered action of the heart, exercise by day did not cause dyspnœa nor any tendency to increase of nocturnal asthma, but after the exercise there were intense headache and giddiness, and often an abnormally slow pulse. It will be noticed that the clinical description of these " asthmatic " attacks differs from that of ordinary asthma in civil life.

Captain Price Jones found that the hæmoglobin percentage was always increased, up to 110 or 120 per cent., in the blood of cases with spasmodic asthma, whereas this change was not found in pure disordered action of the heart from gassing. The red cells were correspondingly increased, the highest count being 6,900,000 per cubic millimetre with hæmoglobin 116 per cent., and a normal colour index. This observation led to a comparison between the late dyspnœa of gassed cases and the well-known dyspnœa and mountain sickness of high altitudes, where oxygen shortage in the air will ultimately cause in many individuals an increase in the number of red corpuscles of the blood. The question was referred to physiologists in England for further study, and a brief discussion of their results is given below.

If this dyspnœa and tachycardia were due to a chronic shortage of oxygen, and this anoxæmia were caused by serious injury to the lungs, it would appear unlikely that the casualties could soon be rendered fit again for duty. But as a matter of practical experience at Hardelot, it was found that a fair proportion of the ordinary run of cases could soon be hardened by careful exercises. All the men were treated as soon as possible by exercises, walking, and other amusements, these being carefully graduated so as to avoid any resulting sense of exhaustion. When a patient could walk 3 miles in one hour without exhaustion or dyspnœa or prolonged tachycardia, he was passed on to the neighbouring convalescent depôt. Patients with spasmodic dyspnœa associated with a high hæmoglobin count, above 106 per cent., did not recover in less than two months and were transferred to England. The simple cases of disordered action of the heart in general recovered well, but there were no satisfactory criteria for an early estimate of what recovery would be, except in the way in which the pulse and the patient reacted to exercise.

Out of 220 cases, 35 per cent. were ultimately transferred to England as needing longer treatment. The remainder were sent back to their units in three months or less as fit for duty. Enquiries were made from the battalions as to the actual fitness of 94 of these men five months after exposure to gas. All but three were either still remaining as fit soldiers with their units or had become casualties from causes unconnected with gas, 13 having already been wounded in action. The proved fit men included nine who had shown nocturnal dyspnœa and four with tachycardia during convalescence up to the end of the sixth or ninth week.

It was therefore evident that the fault in the "wind," whatever its nature might be, was in a large proportion of cases of only a transitory nature, provided that the casualties were hardened to recovery by very easy stages at the commencement. A similarly good and complete recovery was seen, though naturally after longer delay, in many of the much more severe cases, who had suffered from obvious pulmonary œdema with dangerous cyanosis, or with broncho-pneumonia, and had consequently been transferred as early as possible to England.

But a group persisted, partly drawn from the severe cases of pulmonary œdema and partly from those who apparently had not been gravely gassed, in which the "wind" remained bad and the features of disordered action of the heart persisted, in some with a pulse of even 160. Many of these men were naturally of poor physique, and liable in any case to have developed disordered action of the heart under the strain of soldiering. In others it was undoubtedly the result of gassing solely. The condition in some typical cases was made the subject of close study by physiologists in England.

Barcroft* and his colleagues at Cambridge confirmed the observation that some of them showed a persistently high red cell count, that is, a true polycythæmia without reduction of the blood volume and not the transient relative increase seen immediately after gassing. The condition could be reproduced in rabbits after a brief exposure to phosgene or chlorine, when there was first the early concentration of the blood, and after that a steadily developing and persistent increase in the red cell count. Rabbits with this condition two months after gassing had their count restored to normal by life in a chamber containing 40 to 50 per cent. of oxygen or twice the proportion in ordinary air. Similarly good, though not permanent, results were obtained when gas casualties with disordered action of the heart and polycythæmia were placed for five days in a chamber containing 40 to 50 per cent. of oxygen. In the case of the rabbits it was proved microscopically that the respiratory surfaces of the lungs had been damaged by a thickening of the pulmonary epithelium and by a bronchiolitis obliterans. No corresponding examination has been made of the lungs of gas casualties at a late date after exposure. But the close comparison of this condition with that seen in men living for a long time at high altitudes under conditions of oxygen shortage, and the fact that these gas patients were temporarily improved by treatment in the chamber enriched with oxygen, did suggest that the condition was due to a persistent anoxæmia, indirectly weakening the heart, and perhaps itself caused by injury to the lungs.

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* Report No. 4 Chemical Warfare Medical Committee, and *Quart. Journ. of Med.*, 1919, Vol. xiii, p. 179.

Haldane, at Oxford, with clinical assistance from Meakins and Priestley,* developed a different view. This laid emphasis on the rapid shallow type of breathing, and inability to hold the breath for long, that characterized these men. Rapid, shallow breathing, say at 50 a minute, does not adequately ventilate the lungs. In a healthy man it will, if deliberately maintained, eventually lead to giddiness, faintness, and various phenomena of oxygen shortage. In their view the anoxæmia and the consequent debility and circulatory deficiencies might be caused simply by the neurasthenic persistence of the rapid shallow breathing that had first been established when the man was poisoned by gas, brought about through changes in the sensitiveness of the Hering-Breuer reflex in the medulla that depends upon afferent vagal stimuli from the lungs.

Whatever the evidence for anoxæmia might be, and whatever the deeper physiological explanation of this state, the certain fact was that a small proportion of gas casualties did develop an intractable form of disordered action of the heart, and that the tendency to this invalidism was increased if the men were pressed to physical effort too early and too fast at the beginning of convalescence. Some of these men showed polycythæmia, others did not. It is almost certain that the disordered cardiovascular state did not have its pathological origin simply in the mechanical strain thrown on the circulation by the transitory asphyxial congestion after gassing. Some clinicians were inclined to see in it further evidence of a toxic action of phosgene on the muscle of the heart and blood-vessels, akin to that which was originally assumed in explanation of cardiac collapse and death in the acute stages of poisoning. But physiological analysis was always opposed to the acceptance of this view either for the acute cases or for the chronic invalids.

With regard to other sequelæ of poisoning by pulmonary irritants, there is nothing to add to what has been stated in connection with chlorine poisoning. No systematic collection of evidence on this point was made by physicians in England during the war, and no clinical data have been brought together since that time. Pensioners were still seen in 1921 with recurrent dry bronchitis, with asthma, or with intermittent febrile bronchitis undoubtedly caused by gas. There is no evidence that tubercle or any other serious maladies have developed more frequently among them than among any other classes of pensioners. Persistent gastric troubles attributed to gas are either neuroses or appear to have had some other cause. The proportion in which these various ailments appear differs according to the clinical views of different observers. An analysis of some French casualties from lung irritant gases made during 1917 in the Hôpital Necker, Paris, by Professor Achard and Major Flandin gave the following figures :—

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* Reports Nos. 5 and 11, Chemical Warfare Medical Committee.

Total casualties from lung irritants = 452.

Light	38 per cent., or 175
More severe	62 per cent., or 277

277 severer cases	Respiratory troubles.	55 per cent.	Emphysema	64 per cent.
			Chronic bronchitis of pseudo-tubercle	31 per cent.
	Digestive troubles	32 per cent.		
	Cardiac and debility	13 per cent.	Cardiac	34 per cent.
			Debility	66 per cent.

These French observers laid more emphasis on the chronic injury of the lungs than on the weakness of the heart and circulation. At the time when their report was made they had not found that true tuberculous infection followed upon gas poisoning.

Prognosis and Invalidism.

The prognosis during the acute stages of poisoning has been discussed in previous pages, and the main statistics of mortality have also been given. Recovery from the pulmonary œdema itself, even in its most serious form, should be complete in four or five days. Complicating broncho-pneumonia was not very frequent with the phosgene type of irritants, and it was rarely fatal after the second week had been passed. But this complication was naturally more frequent and more serious in men who had been suffering from bronchitis previous to gassing, or had lain out under conditions of exposure after they had become casualties. It was commoner when epidemics of winter bronchitis were prevalent.

Men with pre-existing emphysema or lung disease of course were handicapped in the struggle against pulmonary œdema, since the margin available for respiration was correspondingly less. Old pleural adhesions were probably of little consequence. They were found at autopsies by Captain H. W. Kaye to exist in 30 per cent. of healthy soldiers who had died from other injuries in the war, and the percentage was not higher in deaths from gas. Age had much less influence than might have been expected, and men of forty-five often recovered as completely as men of twenty.

The duration of invalidism subsequent to gassing by lung irritants has not been determined accurately. All through the war gas casualties were treated by medical officers with too much sympathy and without the firmness, based on a clear understanding of the nature of the invalidism, that was necessary to restore them with the least possible loss of time to military efficiency. There was no knowledge available before the war to guide the medical services in the general control of these cases, and the information could only be obtained by taking a large group of gassed soldiers and placing them under control of selected medical officers who were made responsible for determining the times of subsequent invalidism.

Such arrangements were ultimately made at Boulogne, but by the time when they became operative cloud gas attacks had ceased, and the slow stream of shell gas casualties affected by pulmonary irritants was too small and intermittent to make the investigation on a large scale possible. But these arrangements were at once used at Boulogne when the lung irritants were replaced by mustard gas, and it will be seen in dealing with the latter how much benefit was obtained by securing and disseminating medical information which enabled the treatment of gas casualties to be raised everywhere to a uniform level of efficiency.

Chlorine may perhaps have caused more lasting damage to the lungs than did the other irritants. The statistics quoted on p. 387 show that out of a group of 332 cases, which included many of only slight severity, 60 per cent. were transferred to Canada as permanently unfit, and that half of these were still complaining of various disabilities four years later. But in contrast to this record should be considered the fact that another smaller group of more severe cases from chlorine showed a return of 40 per cent. to full duty within two years.

Even grave casualties from lung irritant poisoning showed on the average good recovery among the survivors. Some individual examples of this are given below in connection with the treatment of gassing by lung irritants. The best evidence is that given by an analysis of the after-history of a group of thirty cases with asphyxial cyanosis, and in many cases unconsciousness, from pulmonary œdema caused by phosgene and chlorine in cloud gas attacks of April 1916. They were of a very severe type, though they had not the pallor of circulatory failure. Captain A. S. Hebblethwaite treated them by venesection, and of the thirty cases three died at the casualty clearing station, one had his leg amputated for thrombosis and gangrene caused by the gas, and a fifth was not traced subsequently. The history of the remaining twenty-five was ascertained from army records twelve months later, with some supplementary information from the Ministry of Pensions after the end of the war. Of these men fifteen had been unconscious or delirious in the casualty clearing station at the end of the first day. The later history of the twenty-five was as follows : Unfit—1, at end of seventh month, for disordered action of the heart, a boy of 19 who had been deeply unconscious. Home duty—4, of whom 2 had been unconscious. In the case of one of the unconscious men a pension of 40 per cent. was at first granted after the war for various subjective complaints, but it was soon reduced to *nil*. Duty abroad—20, this medical classification having been made on the average in the fourth month after gassing.

Of those classified for duty abroad, eighteen went to full front line duty as follows. Four went to Salonika or Mesopotamia. All had been unconscious or delirious at the casualty clearing station. One of these men, aged 47, went abroad at the end of three and a half months. Another contracted malaria, for which he received 20 per cent. pension, but *nil* for gassing. Seven went back to France, where one was killed in action at the eleventh month, and another fell sick with enlarged glands not attributed to gas. Of these, four had been unconscious or delirious. Seven went back to full duty in France from the base without having been even transferred to England, although three of them had been unconscious. One of the unconscious men was wounded at the fifth month, and another wounded later ; a third, who had been only cyanosed, was also wounded in action. None of these three men was found to have any disability from gassing when they were pensioned for their wounds. The remaining two out of the twenty were transferred to labour battalions in France, men of 37 and 45 respectively, of whom one had been delirious.

The ages were found to be practically evenly distributed in all the groups of final classification. This record proves clearly that the most severe cases may recover and be fit for duty again in four to six months. The group is too small to show the average percentage of men who became permanently unfit, but it does justify the conclusion that such unfitness is often an accident resulting from the effect of other additional factors, or from unskilful treatment, and that it is not an unavoidable consequence of severe poisoning.

The average grouping of all gas casualties, mild and severe, is illustrated by the following figures. In the cloud gas attacks at the end of April 1916, the battalions that were the most severely exposed to high concentrations lost 10 to 20 per cent. of their strength by gas poisoning. Of these casualties, 18 per cent. died, 45 per cent. (or 55 per cent. of the survivors) were transferred to the United Kingdom as serious cases, and 37 per cent. were returned to duty in France.

The attack of 8th August, 1916, was of a very serious character. The deaths on the total casualties were 46 per cent. But the survivors showed at least as good a recovery as in the earlier and less deadly attacks. The following was their disposal at Boulogne, where a rest station then existed for the special treatment of convalescent gas cases.

Transferred to England for further treatment ..	41	per cent.
Retained in France, fit for duty in from 2 to 3 months	59	,,

Further analysis of the times of recovery for these casualties suggested the following general table of what might have been the approximate invalidism of one hundred survivors from lung irritant poisoning, excluding those who were so mildly affected that they returned in a few days to their fighting units.

Retained for treatment in France		60
Fit for duty in 1 month	30	
,, ,, 2 months	10	
,, ,, 3 ,, ...	20	
Transferred for treatment to England		40
Fit for duty in 4 to 8 months	35	
Permanently unfit	5	
Total		100

As a matter of general experience, apart from statistics, no large group of men was semi-invalided by gas and placed permanently on light duty in France. Nor were there many who had been transferred from fighting units to labour battalions for a similar cause. Lieut.-Colonel W. Best, R.A.M.C., in the spring of 1918, in reviewing 4,000 selected men from labour units who were examined by a medical board at Boulogne with a view to their transfer to fighting units, found that only seventy-five of these men attributed disability to previous gas poisoning, and twenty-eight of these were at once passed as fit for general duty.

The nature of the disabilities among gas casualties revealed by the examinations made under the Ministry of Pensions is considered in Chapter XVII. The disability was on the average slight, but the Ministry of Pensions authorities were unable in their returns to discriminate at so late a date between the various forms of gas that had originally caused the disability.

Treatment.

The essentials of treatment for poisoning by any pulmonary irritant gas are rest, warmth, oxygen, and venesection. The value of the first two is obvious. Venesection and oxygen were tried as soon as casualties from chlorine occurred, but a considerable time elapsed before their utility was accepted as clearly proved, and it is therefore desirable to consider in detail the evidence with regard to these two methods of treatment before passing on to a general statement of how gas casualties should be managed.

Venesection.—Bleeding, to the extent of 15 to 20 oz., has long been regarded in civil medicine as a useful means to lessen acute venous engorgement caused by failure of the heart or obstruction to the circulation through the lungs. In gas poisoning the pulmonary circulation is partly obstructed by the pathological changes that have already been discussed, and there is engorgement of the right side of the heart. But the blood volume is already diminished by the escape of fluid into the lung tissue, and the blood is concentrated and more viscous than normal. When this concentration was discovered by blood-counts, it was at once suggested that it might be advantageous to thin the blood by intravenous saline infusions immediately after relief of the engorgement by blood-letting. No one, however, ventured to try saline infusions on human casualties because it was feared that the immediate result might be an increase of the pulmonary œdema and final asphyxiation.

Venesection alone appeared at any rate to be justified from previous civil experience, and it was strongly recommended by observers (Macaulay and Irvine) who had dealt with casualties in South African mines, where nitrous fumes from high explosives had occasionally been seen to produce a pulmonary œdema precisely like that caused by phosgene, and with the same treacherous delay in the onset of symptoms. Indeed, in these cases it was stated that the development of serious pulmonary œdema could be altogether checked by free venesection prior to the appearance of the usual symptoms of œdema.

During the chlorine attacks venesection was used only in a few cases of advanced and serious cyanosis, and it did not seem to influence their mortality. Later, in the cloud gas attacks of phosgene mixed with chlorine, April and May 1916, the method was tried more carefully and earlier after the gassing, though not at the field ambulances. At No. 33 Casualty Clearing Station at Béthune eight serious cases were bled at about the ninth hour after gassing; seven died. These experiences and other similar results proved to competent judges that in cases of leaden grey or pallid asphyxiation, that is, in the most serious type of fully developed pulmonary œdema with circulatory failure, venesection was not only useless but seemed even to be harmful.

But at a casualty clearing station placed at Lillers farther behind the line, so that it received cases of less urgent gravity and at a later hour after gassing, eighteen to thirty-six hours, venesection was employed with undoubted benefit. It was done soon after admission, the patients being of the blue cyanosed type with venous congestion and full pulse, that is, men who had not developed the rapid circulatory collapse of pallid asphyxia. Controls were chosen and notes taken of the results. A report on thirty of these men published by Captain A. S. Hebblethwaite, R.A.M.C., has been referred to on p. 408. They were all severe cases, and out of the twenty-five whose subsequent history on recovery was traced fifteen had been unconscious or delirious with asphyxia at the casualty clearing station. The immediate results of the venesection were a lessening of the cyanosis, a sense of greater ease felt by the patient, who would often state that his headache and tightness in the chest were relieved, and the induction of quiet sleep. The casualties who were venesected early appeared to do better than the control cases. Their ultimate recovery, as already stated, was good, and it was perhaps more rapid and complete than would have been seen had casualties of such gravity not been treated by bleeding.

Henceforward it became the general rule that blue asphyxial cases with good pulses should be bled as soon as possible. No evidence was ever obtained to show the possible influence of very early venesection as a preventive against the development of serious pulmonary œdema. The question was often discussed, but it was never subjected to a clear test, which could disentangle casualties that would have remained light from those who might conceivably have been expected to become serious if they had not been venesected. Cases of poisoning by pulmonary irritants became few and scattered after 1916, when the cloud gas attacks ceased, and a suitable opportunity for testing this question in the field was never found.

The French were so convinced of the value of free venesection that they crystalized their views in the phrase of the official memorandum that "la saignée pour l'oedème est aussi indispensable que la ligature d'une artère pour l'hémorragie." And the Germans themselves urged its value with equal emphasis, even recommending that if blood would not flow from a cut vein the radial artery should be opened. They thought that early venesection checked the development of pulmonary œdema in addition to reducing the concentration of the blood, and advised its being done not later than six to twelve hours after gassing, and as soon as any apparently mild cases seemed to be developing symptoms suggesting the onset of more severe œdema.

Paradoxically, though venesection was recognized as of real value by those who had to treat casualties in the field, it was long before the physiologists working with gassed animals in England could find proof of its utility. Their early experiments, even with a series of 100 goats, showed no reduction in pulmonary œdema as the result of venesection.* But observations on dogs made in America by Professor F. P. Underhill did prove that bleeding lessened in some way or other the mortality after chlorine poisoning; and his assistants, Lieutenants S. Goldschmidt and D. W. Wilson, in subsequent experiments made in the experimental ground at Porton with chloropicrin and phosgene, were able to give further proof of the value of early venesection and to demonstrate in addition that, when bleeding was combined with the intravenous infusion of isotonic salt solution, still better survival results were obtained. These workers showed that in gassed animals there was a tendency to a preliminary slight dilution of the blood, and that serious blood concentration did not occur until many hours after gassing, the delay naturally varying with the severity of the gassing. When dogs were bled to 1 per cent. of the body-weight one hour after phosgene gassing, and infused with an equal volume of saline solution several hours later as soon as the blood reached a concentration of more than 25 per cent. above normal, the infusion being repeated if the hæmoglobin rose subsequently to 40 per cent. above normal, then the survival-rate was three times as good in animals so treated as in the controls. No evidence appeared in the experiments to suggest that infusion, when performed some time after venesection, led to increase of lung œdema. These observations were not completed until late in 1918 and consequently no attempt was ever made to use intravenous infusion on human casualties. But it does appear that the method would provide a useful means of treatment in cases with pulmonary œdema where the hæmoglobin estimation shows an unduly high concentration of the blood. Apparently the method was actually put to practical test by Laqueur and Magnus, the German investigators, who, however, continued to lay more stress on venesection than on infusion as a means of reducing the abnormal concentration and viscosity of the blood.

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* Report No. 13, Chemical Warfare Medical Committee.

No animal experiments were able to reproduce the condition of grey asphyxial collapse seen in human casualties, and no precise analysis was ever made of this condition.

Oxygen.—The history of the use of oxygen in the treatment of gas casualties was, curiously, the very converse of that of venesection. So soon as it was realized that the asphyxial cyanosis was caused by pulmonary œdema, physiologists urged that it must be possible to alleviate it to some extent by the use of oxygen. Yet, when tried by medical officers, oxygen seemed to do but little good to acute casualties. The fault lay in the method of administration. Oxygen was at first given in the customary old-fashioned way, through a funnel held at some distance from the patient's mouth, and supplied only for such short time as sufficed to bring back the pink colour to the face, when its administration was stopped. The patient soon lapsed into his original cyanosis, and he benefited but little by such fragmentary supplies of oxygen. Despairing of any aid from the addition of oxygen to the inspired air, some officers made fruitless efforts to introduce oxygen into the body by other routes—under the skin, by the rectum, or even by intravenous saline infusion enriched with oxygen. Obviously none of these means could supply the quantity required. The rapid consumption of oxygen by the body was not at first realized, this being so great as to require continuous enrichment of the inspired air with at least two or three litres of oxygen each minute if the respiratory needs of the body, even when resting, were to be met in spite of the hindrance imposed by the pulmonary œdema to the passage of oxygen into the blood.

In the cloud gas attacks of April and May 1916, oxygen was given in a better way, from nitrous oxide anæsthetic apparatus, so that a high concentration was attained, and the administration was kept up with brief intervals for hours. At No. 1 Casualty Clearing Station, Chocques, gravely ill cases were proved to have been saved in this way, and so at last the usefulness of oxygen treatment was firmly established. Major Adrian Stokes, R.A.M.C., when confronted by a great flood of serious casualties in the gas attack of August 1916, introduced a simple method that enabled many cases to be treated simultaneously from one cylinder of oxygen and without the need of an attendant to hold a respiration mask on the face. A vaselined catheter, size No. 8, was introduced for 4 in. through the nose so that its end hung well over the soft palate, and through this a continuous supply of oxygen was maintained. It was necessary that the patient should be encouraged to breathe through the nose and not through the mouth, in order to get the full advantage of oxygen when given in this way. Finally a mask with a valved control of the oxygen cylinder, devised by Professor J. S. Haldane,* was issued to casualty clearing stations. This could be tied on to the patient's face ; it gave a known current of oxygen as long as was needed ; and the valves prevented waste of oxygen during expiration, so that the consumption was cut down by half. The enormous consumption of oxygen had previously made it almost impossible to get enough cylinders for the treatment of a large group of cases at the place and moment where they might suddenly be needed.

Haldane's teaching also led medical officers to realize that the grey cases with circulatory collapse were just as much, or even more, asphyxiated than those with the plum-coloured visage of obvious cyanosis, and that they were in even greater need of oxygen treatment. Oxygen administered in this way was most effective in easing the difficulties under which the circulation was labouring.† It was undoubtedly a great help to the heart, and there were few cases, excepting those in which broncho-pneumonia was present, which could not be made and kept pink by the persistent and abundant use of oxygen.

The following are illustrative cases of the use of oxygen :—

Case 1.—Gassed 1st September, 1916, 11 p.m., an enemy trench mortar having burst an English cylinder of phosgene mixed with chlorine.

2nd September, 3 a.m. : Brought to field ambulance, apparently dying. Semi-conscious, greyish-blue, rapid shallow breathing, pulse very feeble and rapid, slight cough. Given oxygen without cessation through nitrous oxide inhaler; colour soon became nearly normal. Very restless all day, and no sleep for the next two nights. Oxygen treatment was kept up continually.

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* *Brit. Med. Journ.*, 10th February, 1917, and 19th July, 1919; and Report No. 10, Chemical Warfare Medical Committee.

† Douglas in *Journ. of R.A.M.C.*, 1921, Vol. xxxvii, p. 216.

3rd night: Given morphia, gr. ¼; slept in consequence, but became very cyanosed during sleep. Only a little oxygen needed next day.

6th day: Still slightly cyanosed. A little thick yellow expectoration.

The patient recovered without any further incident. He was evacuated to England, and in four months after gassing was discharged to convalescent depôt. At the end of nine months he was classed "A" for duty, and was sent to the Mediterranean. Demobilized on 15th February, 1919, having had no further symptoms from gassing.

Case 2.—Gassed 2nd April, 1917, 6 a.m., by enemy gas shell (?) trichlor-methyl-chloroformate.

10 a.m.: Brought to casualty clearing station, when oxygen was at first given intermittently and unsystematically.

9.50 p.m.: Apparently moribund; livid cyanosis; pulse hardly perceptible and uncountable. Haldane apparatus now used with oxygen at 6 litres a minute. This improved the colour, though even 10 litres a minute did not restore the normal pink. Pulse soon became palpable, but of irregular force, 120 a minute.

3rd April, 1.30 a.m.: Pulse 112, weak, but regular; respirations 58. 3.30 a.m.: Oxygen still continued at 6 litres a minute; patient sleeping. 8 a.m.: Pulse 100; respirations 54; oxygen continued at 5 litres, since 3 litres a minute failed to relieve cyanosis.

Oxygen treatment was progressively lessened. The patient recovered. He was transferred to England on the tenth day, and within a year rejoined his regiment in France, where he was subsequently wounded.

Case 3.—Gassed 31st January, 1917, at 5 a.m., by enemy trench mortar bomb (probably phosgene). Reached casualty clearing station 7 p.m., and treated with pure oxygen for ten minutes every half-hour.

1st February, 10.30 a.m.: Pale and leaden colour; speech incoherent; very weak and semi-comatose. Pulse 130 to 140, weak, low tension and irregular; respirations over 50 per minute. Continuous administration by Haldane apparatus of 5 litres of oxygen per minute started, with intermissions of ten minutes every half-hour. With 5 litres of oxygen per minute the colour of the lips and face became almost normal, though with 3 litres per minute the relief of the cyanosis was far from complete. Remarkable improvement in the pulse in a few moments. Pulse fell to 120 in rate and became of much better volume and tension. If the oxygen was stopped full cyanosis quickly reappeared and the pulse deteriorated greatly in quality.

2nd February: Patient more conscious. Pulse 120, regular and strong. Oxygen supply of 4 litres per minute now sufficient to relieve cyanosis completely. Respirations 44 per minute.

The oxygen administration was continued, the supply of the gas being gradually reduced, till the evening of 4th February, when the administration was stopped altogether, as the cyanosis did not reappear and the patient's general condition had very greatly improved.

In addition to its use in the intense anoxæmia of acute gas poisoning, oxygen was also tried at a much later stage in the treatment of chronic gas casualties. These were men who suffered from a shortness of breath, that was usually associated with tachycardia and rapid breathing, and the evidence has already been given to show that a persistent shortness of oxygen did occasionally appear in chronic cases of gas poisoning, whether this shortage were caused essentially by damage to the lung epithelium or by an altered type of shallow breathing with imperfect ventilation of the lungs.

Investigations were made in England on the treatment of such patients with air enriched by oxygen, either by living for several days in a chamber containing 40 to 50 per cent. of oxygen or by continued respiration through a Haldane mask. Chamber treatment* caused general improvement for a time in the patient's condition and ability for physical effort, and it lessened the polycythæmia which was present in these chronic cases. Actually these chanced to be men who had not suffered from very severe gassing at the onset but had subsequently developed chronic trouble. It was, however, found that men with simple disordered action of the heart from other causes than gas were not improved in the same way by treatment in the chamber. Oxygen administered over a long time, especially at night, through a simple Haldane mask,† also led to improvement in the condition of these chronic cases, with better sleep, lessening of asthmatic tendency, and greater tolerance for physical effort. But it was found to be very difficult to effect any permanent improvement in the shallow type of breathing which in Haldane's view,‡ is probably the fundamental physiological fault in these men, and persists with the general neurasthenia until the latter can be cured by other methods that will brace the individual up to normal health. However, this prolonged oxygen treatment of chronic invalids hardly enters into the field of view of military medicine. It might in some cases, at a great expenditure of oxygen, alleviate the disabilities of the men, but it could not restore them to fitness for full military duties. As will be seen later, it is probable that skilled care of the casualties during the time of early convalescence can largely diminish the proportion of men who ultimately develop these features of disordered action of the heart with shortness of breath.

Treatment immediately after Exposure to Gas.—The first difficulty is that of deciding whether a man has really been gassed. Fear or malingering may induce a soldier, when gas has been in the air, to assert that he is gassed when really he has not suffered in any way. On the other hand, it must be remembered that many of the lung irritants have a delayed action, and that very grave symptoms may develop in a few hours in men who think at first that they have escaped unhurt. The benefit of the doubt must, therefore, always be given to the patient; it can, however, be assumed with safety that if no objective features of gassing have appeared after a lapse of forty-eight hours, then the degree of gassing was slight and the case may be returned to duty without further delay.

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* See Bibliography, Barcroft and others; Report No. 4, Chemical Warfare Medical Committee; *Quarterly Journal of Medicine*, and the *Proceedings of the Royal Society of Medicine*.

† Report No. 11, Chemical Warfare Medical Committee.

‡ *Journ. of R.A.M.C.*, 1919, Vol. xxxiii.

On first examination, the man should be asked to describe his own symptoms and no leading questions should be put. Vomiting may have occurred or there may have been a sense of exhaustion. Pallor of the face, a rapid pulse, unusually short and rapid breathing, are all helpful signs. If a man cannot take a deep breath without pain or coughing, that is also presumptive evidence of gassing. If any of these features are present, the patient must be treated with the utmost care. No drugs are of particular value at this stage, but the casualty must be saved from all undue muscular exertion. He should, if possible, be spared the effort of walking and should at once be relieved of all equipment. The importance of complete muscular rest cannot be exaggerated. On the other hand, it is equally important that casualties should be evacuated with the least possible delay to medical units where skilled nursing and proper remedial measures may be available so soon as any patient shows features of acute pulmonary œdema.

Treatment in the Acute Stage of Poisoning.—Rest is the chief essential. Undue muscular effort may aggravate the development of pulmonary œdema, and it certainly increases the consumption of oxygen at the very time when the œdematous lungs are incapable of supplying more than a minimal quantity to the circulation. The men should be kept in any posture that is comfortable to them. Those who show features of serious poisoning should not be allowed to leave their bed or stretcher for any purpose whatsoever. If the restlessness is extreme, a small dose of morphia, gr. $\frac{1}{6}$, may be used once to quieten the patient, but the dangerously depressant action of the drug on the respiratory centre must be borne in mind. Uniform should be exchanged for hospital clothing wherever practicable. The pure pulmonary irritants do not adhere for long to clothing during exposure, but the lachrymators, the arsenic Blue Cross substances and mustard gas do so, and the general rule should therefore be observed with all casualties. Otherwise the patient is exposed to a longer action of the poison, and, moreover, even the hospital staff may be affected. Warmth must be maintained. It helps to lessen shock and also diminishes oxygen consumption that would otherwise be entailed by the muscular movements of shivering.

Venesection to the extent of 15 or 20 oz. should be performed as early as possible on all cases of blue cyanosis with a full rapid pulse. It is not advisable for the serious cases of early collapse with greyish pallor and a rapid, thready pulse. Free venesection lessens a man's vigour for a couple of weeks ; it is only of value in cases of poisoning by pulmonary irritants, being useless for mustard gas, and it has not been proved to have great prophylactic value against the development of pulmonary œdema. Therefore, under conditions of fighting, where all temporary loss of man power must be curtailed, it seems on the whole better that venesection should be used only for casualties who have passed beyond the stage of mild poisoning.

Oxygen should always be given to casualties with serious pulmonary œdema, that is, to men with intense blue cyanosis or grey pallor. These need oxygen continuously and over a long period. If the supply permits of such use, it should be given also to milder cases of œdema in order to prevent their lapsing into a more serious state of asphyxia. It should be remembered that in every autopsy on early death from pulmonary irritant poisoning, extreme œdema of the lungs was found, that cyanosis is the main indication of such œdema, and that no case in whom it was possible to restore a pink colour by the proper use of oxygen died of this pulmonary œdema. The oxygen, which does not require to be warmed, must be given with some special apparatus, such as a Haldane mask or nasal catheter, that will ensure its being adequately commingled with the respired air. The minimal current of oxygen should be used, from two up to even ten litres enrichment per minute, which will suffice to keep the patient's face pink, a change that is usually associated with improvement of the pulse ; and the treatment must be maintained, even for one or two days and nights with progressive lessening of the oxygen supply, until recovery is assured and the patient does not lapse into cyanosis when the oxygen is intermitted. If no other apparatus is available than the nitrous oxide anæsthetic apparatus, which delivers pure oxygen from the cylinder (the valve of the bag being, of course, set so that the patient expires into the air and does not breathe in and out of the bag), should be used intermittently, say at alternating intervals of five minutes, because pure oxygen may eventually be irritant to the lungs.

Serious cases are best kept in a well-ventilated ward rather than in the air, where they may become cold. Expectoration may be encouraged by some postural device. Artificial respiration by Schæfer's method was in a few semi-comatose cases found to be of value in expelling fluid from the lungs, though great care was needed in its use. Vomiting is also helpful in emptying the lungs, and if it does not occur naturally it may be excited by simple measures such as tickling the back of the throat or by drinking salt and water. But vomiting is liable to produce exhaustion and it should not be induced by powerful drugs such as ipecacuanha. Pain in the stomach will often yield to doses of sodium bicarbonate. Food should at first be fluid and sparingly given, the bowels being kept open. Thirst is constant and the patient may be allowed to drink freely of lemonade, weak tea, or simple water.

No drugs were found to be of any special value, though many remedies were tried. Glass ampoules of ammonia were at first used on a large scale for inhalation soon after exposure to chlorine and phosgene gases. It was thought that the vapour might lessen bronchial spasm and perhaps neutralize acid formed in the lungs. The ampoules were certainly welcomed as a useful stimulant by mild cases, but the ammonia seemed to add to the dyspnœa of severe casualties. In the French service the use of ammonia was forbidden and capsules of ether were relied upon. Some early remedy of this nature is undoubtedly of great assistance, for casualties regain confidence if they are given to breathe for a moment some " anti-poison gas " vapour that eases their pain or sense of respiratory distress.

Atropine was also used freely in 1916 on early cases with hope of lessening bronchial spasm and pulmonary œdema. Carefully collected evidence showed nothing in its favour. Morphia was dangerous, and should only be used to control restlessness. Aspirin and phenacetin were forbidden in the treatment of the headache of asphyxial congestion, since it was supposed that their use might weaken the circulation. The best cardiac stimulant was oxygen, and next to that brandy, pituitrin, or camphor (10 min. hypodermically of camphor 1 gr., olive oil 5 min., ether 5 min.). Ordinary expectorant drugs should not be given until after the second or third day, when they are helpful in checking the possible development of infective bronchitis.

Treatment during the Convalescent Stage.—No case should be evacuated to lines of communication until definite cyanosis or severe symptoms have disappeared, since a long journey without close nursing attention during this time of danger may have most serious results. It is also most important that when cases who have passed through a condition of gravity are finally evacuated to another hospital, a note of the special symptoms should be made on the field medical card in order that subsequent treatment during convalescence may be rightly controlled.

Men who suffered with genuine broncho-pneumonia required a long rest, and were evacuated to home hospitals. Those who have passed through a stage of severe cyanosis, perhaps with unconsciousness, should be similarly treated, however complete their apparent recovery in the second week. The other cases will soon become fit again for duty, and in a short time they can be put on to training exercises which will differentiate the mildly affected men from those who recover more slowly. But it is essential that all who have really been casualties should, in the first two or three weeks, be given opportunities for lying down and resting during the day time between their periods of exercise. Without such precautions men are liable to become more exhausted in their period of convalescence, and symptoms of disordered action of the heart may develop and cause many unnecessary weeks or even months to be added to the period of convalescence. With this safeguard all except the severer casualties should be got up from bed as soon as possible after the first few days. Slight bronchitis and gastric disturbances, which usually are only temporary, do not contraindicate this. Cases of abnormally rapid or slow pulses should be rested a little longer. The remainder should in the second or third week be tested and slowly hardened by carefully graduated walking exercises with intervals of rest between. Shortness of breath, tachycardia, or a sense of exhaustion after effort are indications that the exercise is not being well tolerated, and men with such features require careful personal attention lest their training be forced too rapidly. The development of an intractable disordered action of the heart is rare, and it should not occur except in men whose poor physique made them liable to this trouble or in those who had been utterly exhausted by long campaigning prior to the final gassing.

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CHAPTER XIII.

VESICANTS. MUSTARD GAS.

THE only warfare gas of this group employed was that colloquially known as "mustard gas." A reference to the tables in the narrative will indicate the preponderating influence on gas casualties which it gradually came to exercise. In the late stages of the war it was computed that between 70 and 80 per cent. of admissions for gas were due to this substance.

Dichlor-ethyl-sulphide (thio-diglycol-chloride) has the chemical formula $(CH_2Cl.CH_2)_2S$. It is, when in the pure state, a clear, colourless, heavy and somewhat oily fluid, which possesses only a very faint odour, suggestive of mustard. When in the crude state characteristic of the contents of the German mustard gas shell it takes on a darker hue resembling a brown sherry. Its boiling point is 217°, its melting point 13°, and its vapour pressure in millimetres of mercury is at 10° C., 0·01 ; at 20° C., 0·06, and at 30° C., 0·09. The liquid is almost insoluble in water, slightly soluble in paraffin or vaseline, but freely soluble in all animal and vegetable oils and fats. It is very slowly hydrolyzed by water ; alkaline solutions, such as sodium bicarbonate, cause a very slow decomposition, but dry chloride of lime rapidly destroys it.

The crude fluid has a rather more pronounced odour than pure mustard gas, but except to those with a fairly keen sense of smell it is not one which is either quickly detected or offensive. In an area heavily shelled with mustard gas the slightly pungent, mustard-like odour may be readily perceptible on first entering the area, but the sense of smell soon becomes dulled and the odour may cease to be appreciated after a short time, a fact of serious importance, for troops are only too likely to underestimate the danger in the absence of the warning afforded by strong odour or immediate irritant effects on the sensory nerves. The characteristic though slight smell of dichlor-ethyl-sulphide suggested the designation "mustard gas" when the poison was first used against the British at Ypres, and this name was habitually used by both the British and the Americans throughout the remainder of the war.

Another common synonym was "Yellow Cross," a term originating in the distinctive marking employed by the Germans for shells containing this substance. In the French armies it was almost invariably known as "yperite," as already noted. The Italians, copying the French, used the term "yprite."

When employed in shells for hostile purposes the dichlor-ethyl-sulphide was always mixed with 15 to 20 per cent. of various solvents. The common solvents used were carbon tetrachloride, dichlor-methylether, chlorobenzene, and nitrobenzene, the object of using these solvents being to lower the melting point and increase the vaporizing properties.

The employment of a fluid introduced a new set of problems, both as regards protection and soil contamination. The effect of the explosion of such a shell was that its contents were spread partly as vapour and partly as a fine spray which was distributed more or less evenly over a radius of some twenty yards. When the spray fell to the ground it remained for a long time on the contaminated area, only slowly being hydrolyzed or evaporating. In fact on dry soil which was not exposed to direct sunlight the contamination might persist for many days and continue to form a source of danger to troops advancing over that area. Particularly was this the case in woods and deep trenches, where neither wind nor sun could exercise much influence. The intense bombardment of the Fôret de Nieppe in 1918 rendered this tract of wood practically uninhabitable to British troops.

Mode of Action.

The essential action of mustard gas is that it behaves as a chemical irritant, inflicting a local burn on any part of the human body with which it comes in contact. When this fact is borne in mind, its pathological action and the morbid conditions arising therefrom are easily understood. Naturally, the exposed skin surfaces are those which suffer first and most severely. An exposed area of skin will receive an injury even if the vapour given off by the fluid in a test tube is allowed to act on it. Still more intense will the action be if the skin be splashed by minute drops of the fluid, such as result when a shell burst occurs in the vicinity.

In addition to the areas of skin exposed, it was found that the moister areas of skin, even when protected by clothing, suffered more than the drier areas. The eyes equally with the face exposed to the action of the vapour were affected by the chemical burns, and conjunctivitis of varying degrees was, therefore, a marked feature.

Lastly, the respiratory tract from the nose to the final bronchi was also a vulnerable area when the vapour was respired.

The severity of all these varied lesions was dependent in part on the concentration of vapour or fluid to which they were exposed, and in part on the secondary bacterial invasion which almost inevitably resulted. Just as in civil practice a burn inflicted by ordinary causes will vary in the initial severity and in the subsequent sepsis, so did the lesions of mustard gas, wherever they might occur, vary in severity and in the after complications.

The burn produced by mustard gas was not, however, immediate in appearance. A delay varying from between two to eight hours invariably followed exposure before the first sign of trouble appeared. The suggestion that this delay was the result of the breaking up of mustard gas and the formation of hydrochloric acid, and that this product was the actual cause of the injuries, has not been proved by experiment. As far as satisfactory proof has been collected, the sole action of mustard gas is the direct action on surfaces with which it is brought into intimate contact, and there is no proof that its action is due in any way to absorption and conveyance by the blood-stream to parts remote from the point of contact or exposure.

It is true that, if given either subcutaneously or intravenously to animals, death with varying lesions can easily be caused. In such experiments it was found that for rabbits a subcutaneous dose of about 0·033 c.c. was nearly always a lethal one. Death in these experiments followed within ten to twelve days. The essential lesion found *post mortem* was an intense congestion of the gastro-intestinal tract, and diarrhœa was always a pronounced symptom in the course of the illness. The characteristic lesions produced in the lungs and skin by exposure to the vapour were not reproduced when the poison was given subcutaneously, provided due precautions were taken to prevent any vapour reaching the animal from the needle. When given intravenously, a dose of 0·06 c.c. caused death within a few hours in the rabbit, and autopsy shows marked hyperæmia of the lungs accompanied by numerous small hæmorrhages into the lung substance. Death was preceded by general convulsions and great prostration. The suggestion that this profound disturbance was the result of the breaking up of mustard gas and the formation of hydrochloric acid was not confirmed when hydrochloric acid in a similar dose was given intravenously, the animal showing no prostration, having no convulsions, and surviving with apparently little ill-effect. Here again, therefore, such evidence as is available would go to prove that it was the direct action of the substance itself on the cell elements of the body that caused the fatal termination, and one must regard it as a true cell poison. It was also shown that urotropine, though capable of neutralizing mustard gas in solution outside the body, could not, when injected intravenously in rabbits, avert the poisonous effects of subcutaneous injections of mustard gas.

Experimental investigations of the lesions caused by mustard gas were made on an extensive scale during the war both by the Allies and by the Germans, and the results were in close agreement with the lesions observed in the field. Since the war, French, American, and German investigators have published exhaustive accounts of these observations.

Morbid Anatomy.

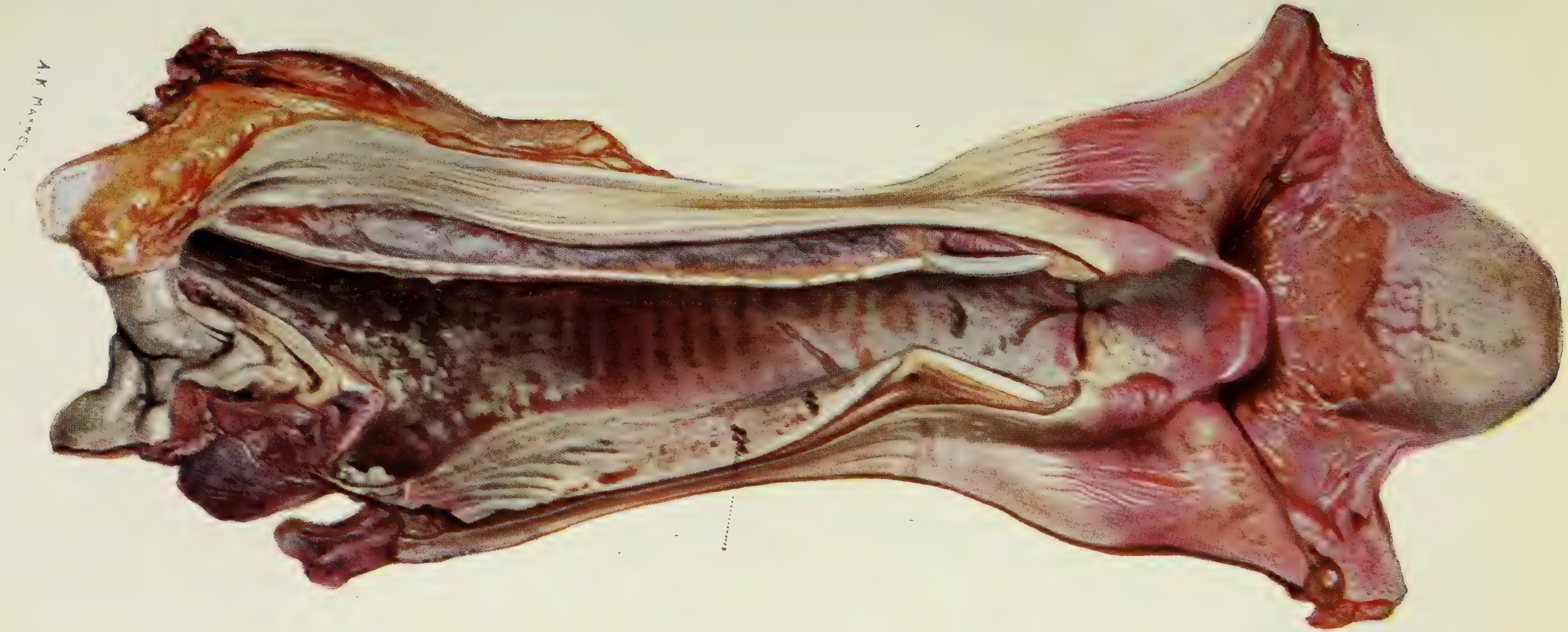
The most important pathological changes to be found in the human body after exposure to mustard gas are those in the respiratory tract. From the anterior nares down to the finest ramifications of the bronchial tree the mucous membrane is intensely inflamed and shows in varying degree the caustic effect of this acute irritant. The destruction of the membrane may have proceeded to such an extent that the whole area of the trachea and the larger bronchi is covered by a loosely adherent false membrane or slough of a yellow colour several millimetres thick. Occasionally the slough on the trachea and larger bronchi can be separated as a whole and removed, giving the appearance of a cast of the bronchial tree. Such a cast has on occasions been coughed up during life (Fig. 1).

On removing this slough a raw, granulating surface is exposed which may, in late cases, be pitted with minute ulcers (Plate V).

The interior of the nose and naso-pharynx may exhibit a similar pathological change.

The lungs themselves are somewhat voluminous, and completely fill the thoracic cavity. When the chest is opened small petechial hæmorrhages may be observed on the pleural surface, but it is not common to find much pleural exudation. In cases where death has taken place early, the lungs on section will be found to contain areas of emphysema alternating with small patches of collapse, and small hæmorrhages will also

PLATE V.



Ulceration of trachea by mustard gas, at the twelfth day after gassing. The reddening of the base of the tongue and of the pharynx, with a sharp delimitation where the œsophagus has refused ingress to the toxic vapour, is seen also with chlorine and other irritant gases. Yellow necrotic sloughs lie on the larynx and at the bifurcation of the trachea. Between these the trachea is red and glistening, because it is now completely deluded of both mucous membrane and of slough. The dotted line points to a little group of ulcers on the posterior wall from which bleeding has occurred.

be visible to the naked eye. The lung, however, on section is dry, and in this respect forms a marked contrast to the *post-mortem* appearances following lung irritant poisoning, in which the lungs, though voluminous, are saturated with œdema fluid, which pours out on section.

In cases which have survived to a later period, in addition to the appearances described above, which are to be regarded as the result of inflammatory reaction, the signs of a secondary septic infection appear ; for, as a result of the intense irritation of the bronchial tubes, pus is secreted which gradually gravitates downwards and sets up a process of broncho-pneumonia.

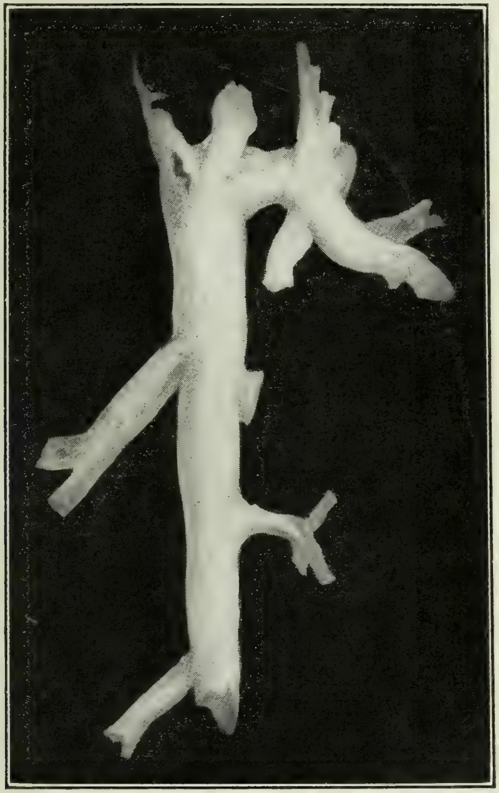


Fig. 1.—Drawing of cast from lower end of trachea and bronchi, which was expectorated at sixtieth hour after severe poisoning by dichlor-ethyl-sulphide (29th July, 1917). Casualty died two days later from broncho-pneumonia. The cast is hollow; its external surface is smooth, and its substance consists only of necrosed epithelium.

In late stages, indeed, the whole of the lower lobes may be practically solid from the confluence of numerous patches of this broncho-pneumonia. Owing to their septic origin, many of these patches tend to break down and form small abscess cavities. On section of such a lung pus will be seen to exude from all the fine bronchial tubes. As a mechanical result of the patches of broncho-pneumonia, the intervening areas of lung which are not consolidated are frequently œdematous, but this œdema is a secondary and partial effect in contrast with the primary and general condition induced by phosgene.

The skin exhibits all stages of burn from the primary erythema, which is the first manifestation of the cutaneous irritation, up to the final stage of a deep burn with necrosis and sloughing of tissues. The latter condition, of course, is only seen where life has been maintained for a considerable period, and ordinarily in the fatal case the skin lesions will not have proceeded beyond the stage of vesication and stripping of the epidermal layers.

Microscopically, the main changes seen in the skin are the damage to the blood-vessels, which are collapsed but not thrombosed, the formation of tissue œdema, with liquefaction of superficial cells, and an underlying vascular and lymphatic congestion of the subcutaneous tissues. Subsequently the ordinary process of eschar formation, with infiltration of leucocytes, takes place, followed by cicatrization and healing. The resulting scar is usually pigmented for a long period.

The eyes share in the general inflammation of the skin, and exhibit all the stages of an acute conjunctivitis, from the early chemosis up to an ulcerative keratitis.

The abdominal organs show very few lesions. The mucous membrane of the stomach may be injected and contain a few small hæmorrhages. The intestinal tract, as a rule, escapes entirely, in contrast with the results seen in animals after subcutaneous injection, although occasionally the upper part of the small intestine shares in the inflammatory changes seen in the stomach. There are no characteristic changes to be seen in the kidneys beyond the congestive swelling and occasionally, on stripping the capsule, subcortical hæmorrhages.

The blood shows no hæmoglobinæmia or other special changes. Some observations suggested a decrease in the coagulation time. There is an early leucocytosis, especially of the polymorphs, and a leucopenia when the case is drifting to death.* The figures for the blood-count are very similar to those for ordinary broncho-pneumonic infections of the lungs.

Punctate hæmorrhages have occasionally been seen in the white matter of the brain, but this condition is by no means so common as in phosgene poisoning, where it is a marked characteristic. The absence of cyanosis and marked oxygen want in these casualties is the probable explanation of the rarity of punctate hæmorrhages.

This brief description of the pathological changes commonly observed indicates that the action of mustard gas is entirely local, and no evidence is forthcoming from *post-mortem* examinations that a systemic as compared with a local poisoning has taken place. Very widespread lesions of the skin have frequently been observed in men who, having worn their respirators properly, sustained no conjunctival or bronchial irritation. Had absorption taken place through the skin, some pathological results elsewhere would reasonably have been expected.

The main pathological lesions which cause death are, therefore, as follows :—

An acute inflammation of the air passages from the larynx downwards, followed by entire desquamation of the mucous lining, with a remarkable formation of false membrane. This membrane, in addition to the actual obstructive effects it produces, affords a suitable pabulum for organisms. An acute purulent capillary bronchitis is superadded, leading to collapse of lung tissue and then to broncho-pneumonia. The acute emphysema which forms a prominent feature of the lung lesions is explicable as a result of a mechanical obstruction in the air passages. Further, the effects of burns leading to a general septic infection will be found in the late cases, and occasionally an inflammation of the mucous membrane of the large intestine.

Reports on the *post-mortem* findings in all cases of death from gas poisoning were furnished as a routine to the D.G.M.S. The following protocols of examinations carried out by Major J. W. McNee at No. 3 Mobile Laboratory in August 1917 will illustrate the changes seen with mustard gas :—

Case 1.—Exposed to mustard gas on the morning of 28th July, 1917. Admitted to casualty clearing station on the evening of 29th July, suffering from severe conjunctivitis and superficial burns of the face, neck, and scrotum.

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* Report by Stewart, No. 17, Chemical Warfare Medical Committee.

Respiratory symptoms gradually developed and death occurred about one hundred hours after exposure to the gas. The autopsy was made very soon after death.

General Appearance.—Superficial burns on the face, neck, and scrotum with blistering. No rash on other parts of the body. Conjunctivæ injected and considerable purulent discharge present. Well-marked œdema of both lower limbs below the knees, " pitting " on pressure being readily obtained.

Thorax.—Pericardial sac contained about 2 oz. of clear fluid. Heart in systole. Right auricle much distended, but not the other cavities. No *ante-mortem* clot found. Both pleural sacs normal and free from adhesions. Lungs fairly voluminous and did not collapse on opening the chest The pharynx showed only a slight degree of congestion, but the uvula was very œdematous. The whole mucous membrane of larynx and trachea appeared to be stripped off, leaving a bare granular surface dotted throughout with small irregular hæmorrhages. When the trachea was opened, it was found about half full of thin obviously purulent fluid, which welled up from the larger bronchi. The surfaces of the lungs showed scanty minute sub-pleural hæmorrhages and many areas of obvious emphysema of lobular distribution. Small depressed areas of collapse were also noted. From the larger bronchi, on section, membranous casts could be pulled out so as to preserve their cylindrical shape. No œdema of the lungs was evident anywhere, but there was extensive fine emphysema. All the bronchi and bronchioles were filled with yellow purulent material, and surrounding many of the smaller bronchi a bright red ring of hæmorrhage was present. No areas of broncho-pneumonic consolidation were evident microscopically.

Abdomen.—Liver somewhat congested, but otherwise normal. Spleen small and firm. The kidneys were both very large, weighing 260 and 230 grm. The capsules were easily stripped, to show a surface of purplish colour and dotted all over with small hæmorrhages. On section both cortex and medulla showed intense congestion, and many small hæmorrhages were visible. Stomach small and contracted. Fairly numerous petechial hæmorrhages below the mucosa, especially in the region of the greater curvature. No hæmorrhages seen in the intestines. Œsophagus normal. The skin of the scrotum was severely burned, but the testicles were normal on section.

Head.—Meninges normal. The brain on section showed no definite congestion, and no obvious hæmorrhages. One retina was examined and found normal.

Case 2.—Exposed to shell gas on early morning of 29th July, 1917. Admitted to casualty clearing station at Merville on same day. Died five days afterwards. The external surface of the body showed little sign of burning, except for some blistering on the scrotum.

Thorax.—Small recent pleuritic adhesions over the lateral aspect of the left lung, right pleural sac normal. Pharynx, larynx and trachea removed intact along with the lungs. Intense purple congestion of entire pharynx and larynx. The trachea showed complete stripping of the whole mucosa, leaving a clean surface studded all over with hæmorrhages. False membrane, forming practically a complete cast of the trachea, had been coughed up by this patient during life, about sixty hours after gassing (Fig. 1). The larger bronchi showed intense congestion and well-marked membrane formation.

Lungs fairly voluminous, but not œdematous in section. Emphysema very marked throughout both lungs, and also irregular patches of broncho-pneumonia. The smaller bronchi were filled with pus, and some were surrounded by hæmorrhage.

Abdomen.—Liver congested, but otherwise normal. Spleen small and firm, with irregular patches of extreme congestion or hæmorrhage. Left kidney entirely cystic throughout. Right kidney of normal size ; capsule stripped readily. The cortex was congested, and the markings somewhat blurred. Stomach had very scanty submucous hæmorrhages.

Head.—Intense congestion of the meningeal vessels. Brain tissue very wet on section, but free from obvious hæmorrhages. Both retinæ examined and found normal.

The urine from this case was examined on 3rd August, 1917, and gave a heavy cloud of albumen (slightly less than half part Esbach). In the centrifugalized sediment granular casts were found in fair numbers.

Case 3.—Exposed to mustard gas during early morning of 29th July, 1917. Admitted to casualty clearing station on 31st. Died six days after exposure to gas. Autopsy very soon after death. Extensive burning and blistering of the skin of face, neck, abdomen, and scrotum. One large blister occupied practically the whole surface of the anterior abdominal wall. Blistering also found on both feet in a situation which must have been covered by the boots if they were on at the time of exposure. Marked *post-mortem* lividity of all the dependent parts of the body, but in addition a definitely purpuric rash extended over the upper arms and front of the thighs. Other portions of the skin of the body and limbs appeared of a dull brownish colour.

Thorax.—Pharynx, larynx, trachea and lungs removed together. The posterior portion of the tongue, and the whole pharynx, showed intense purple congestion, without ulceration. The uvula was short but very much swollen. On opening the larynx and trachea a very advanced lesion was met with. The stripping of the mucosa, and small hæmorrhages were both very extreme. The lumen of the trachea and larger bronchi were quite filled with a mixture of thin pus and semi-adherent whitish membrane. Large flakes of similar membrane were occupying the lumina of all the larger bronchi. The lungs were voluminous, although not nearly to the extent commonly found in cases of phosgene poisoning. Very numerous petechial hæmorrhages were seen below the visceral pleura. On section much fine emphysema, with some collapse, was the chief lesion observed. Towards the bases, however, where a fairly advanced patchy broncho-pneumonia had developed, the lung tissue was frankly œdematous, and much fluid could be squeezed out from the cut surface. The smaller bronchi were all filled with thin pus.

Abdomen.—Liver yellowish in colour and greasy to touch. In section obvious fatty change present. Spleen firm and uniformly congested. Kidneys both of normal size ; capsules not adherent. Cortex showed marked congestion but nothing else macroscopically. Stomach wall had very abundant submucous hæmorrhages scattered irregularly over the surface, but most abundant towards the pyloric end and on the greater curvature. Œsophagus normal. Intestines normal.

Head.—Meninges showed some œdema and vascular congestion. Brain substance in section unduly wet. Very marked puncta cruenta, but no definite hæmorrhages.

The urine of this case was examined on 3rd August, 1917, and contained no albumen or casts.

Case 4.—Aged 39 years. Gassed in a town on the early morning of 29th July 1917. Admitted to casualty clearing station on same day. Died about ten days later. This case developed bronchial symptoms very early.

Brownish pigmentation present over large surfaces of the body, especially marked on the outer aspect of the thighs, over the knees, round the elbows and on the deltoid region. The forearms showed the same pigmentation, except at the place where a wrist watch had been situated, a white ring of skin being present there. Marked superficial burning of the face and scrotum. The air passages were removed complete along with the lungs. The pharynx was much congested, but the tongue and uvula little affected. The whole of the trachea and lower part of the larynx, including the vocal cords, were covered by a yellowish membrane fairly easily detached from the underlying structures. The upper half of the larynx was uncovered by membrane, but very red and congested. On stripping off the membrane from the trachea, an intensely red surface, resembling granulation tissue, was revealed. The bronchi contained abundant pus, and the lymphatic glands near the roots of the lungs were enlarged and congested.

Both pleural sacs were normal and free from adhesions except for small patches on the lateral surfaces. The lungs were fairly voluminous, and completely filled the thoracic cavities. The right lung showed extensive collapse at the base, the lowest lobe being almost completely carnified. The upper lobes were emphysematous and firm patches of consolidation could be felt below the pleura. This lung was kept as a specimen and was not incised.

The left lung showed also some collapse at the base, but only in small areas. On section numerous patches of broncho-pneumonia, some as large as a five shilling-piece, and all standing out very prominently from the emphysematous tissue around, were found scattered throughout both lobes. These patches were grey in colour, and in many of them the pus could be seen to have extended beyond the limits of the bronchi to form definite abscesses. In other parts of the lung well-marked purulent capillary bronchitis was manifest. Heart contracted in systole. Both ventricles contained *ante-mortem* white clot. Heart muscle apparently healthy.

Abdomen.—Liver congested and somewhat fatty. Spleen not enlarged, pulp soft and rather diffluent. Kidneys both large, each weighing about 220 grm. Capsules non-adherent. Cortex congested and the markings slightly indistinct.

Stomach showed fairly numerous submucous hæmorrhages, chiefly towards the pylorus. Œsophagus normal.

Head.—Great congestion of the meningeal and cortical vessels. The brain substance was unduly wet on section and very congested. No hæmorrhages found.

The urine from this case was examined three days before death, and contained the faintest trace of albumen, but no casts.

Microscopic Anatomy.

Microscopic examination bears out the naked-eye observations, the lesions being essentially those caused by a necrosis of mucous membrane followed by a secondary broncho-pneumonia. The following account of the histological findings by Major McNee and Captain Shaw Dunn gives in detail the changes seen, and is based on examination of tissues from eighteen cases :—

Earlier Microscopic Lesions.—The most clear-cut early lesions of the lungs are shown in a case which survived for forty hours after gassing. Sections from this case show extensive emphysema, and intense congestion of the alveolar capillaries. Many of the alveoli contain catarrhal cells and scanty red blood-corpuscles, but œdema is minimal in amount. Well-marked purulent bronchitis and bronchiolitis are present. Each small bronchus is surrounded by a definite ring of hæmorrhage into the lung tissue, which appears as a bright red circle in a hæmalum and eosin stained section when looked at with the naked eye. Proceeding towards the lumen, the wall of the bronchus is normal as far as the basement membrane, except for slight hæmorrhage and leucocytic infiltration. The cells of the mucosa have almost disappeared, and those left *in situ* are entirely necrotic. Replacing the mucous membrane is a remarkable formation of false membrane of considerable thickness, formed of an irregular, fairly dense network of fibrin and leucocytes which stains pink with eosin. Within the meshes of the fibrin network many masses of bacteria can be recognized. The central part of the lumen of the bronchi is filled by a collection of loosely arranged polymorphonuclear leucocytes. The trachea in this case showed almost complete stripping of the

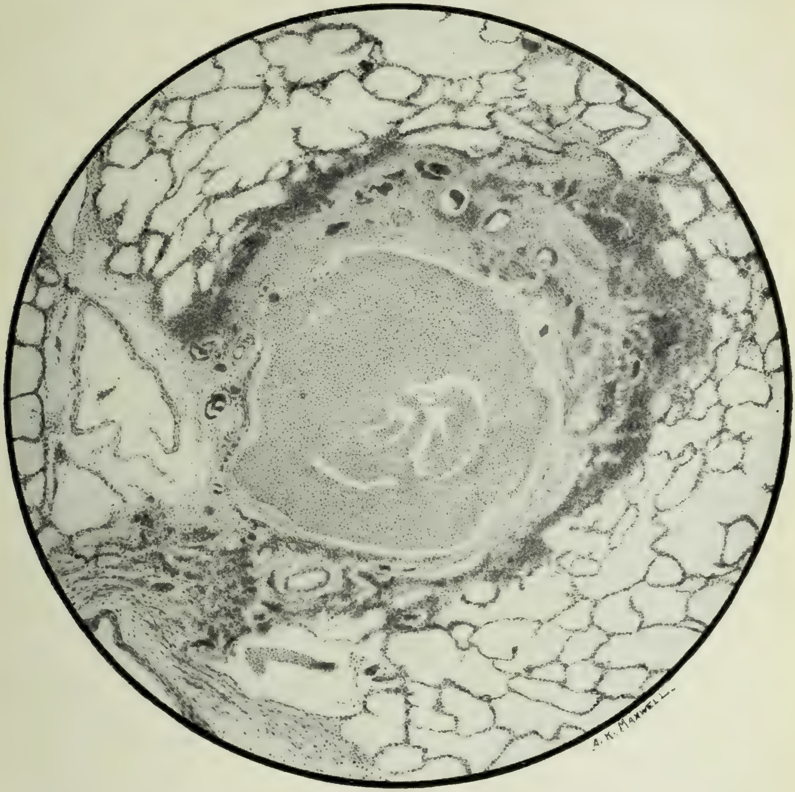

Fig. 2.—Microscopic section of human lung from mustard gas poisoning, with death at the end of second day (forty hours). The bronchiole is filled with fibrin and pus cells, and its lining epithelium has been completely destroyed. The inflammation has caused a characteristic ring of hæmorrhage in the tissues around the bronchial tube, and infection is beginning to appear in the alveoli nearest to these inflamed tissues. There is no generalized pulmonary œdema and no disruptive emphysema. The pathological changes in the bronchioles and in the alveoli are therefore in the sharpest contrast with those caused by phosgene.

mucosa, with a layer of false membrane, of the usual structure, almost as thick as the whole tracheal wall. Sections from the lungs of other early cases confirm the above description, but in some the conditions have progressed still further to the development of patches of broncho-pneumonic consolidation.

The trachea in the early cases is stripped of its mucosa so as to expose the basement membrane, on which is superimposed a thick layer of false membrane similar to that found in the bronchi. This membrane, in cases of only two or three days' duration, is still firmly adherent and regular, whereas later it tends to become partially or wholly detached.

The liver in the earlier cases exhibited no lesion recognizable under the microscope. The spleen pulp showed a variable amount of congestion but never of extreme degree.

With regard to the kidneys, no very definite conclusions could be arrived at among the early cases, as in all of them some autolysis had taken place. The glomeruli appeared markedly congested in every instance, but were otherwise unaltered. Desquamation of tubular cells and loss of nuclear staining were common, but owing to the autolytic changes no real significance could be attached to this.

The brain in two of the cases which did not survive longer than three days showed multiple hæmorrhages of very small size, only recognizable microscopically, and quite irregular in shape. These were quite different from the typical "ring" shaped hæmorrhages in the white matter in phosgene poisoning. In the other cases no hæmorrhages were found.

Later Microscopic Changes.—The changes in the lungs were all of similar type and may be conveniently summarized for all the cases surviving for a period of five days or more. No definite line can, of course, be fixed between the earlier and later changes, as the lesion had progressed much more quickly in some lungs than in others. The later changes were, briefly, the development of patchy broncho-pneumonia, collapse of portions of lung tissue and even more marked emphysema than earlier in the illness. Frequently all these three lesions could be observed side by side in the same small block of lung tissue taken for examination. All of these changes are natural sequels of the purulent capillary bronchitis met with at first.

The trachea in these later cases was also completely bared of epithelium, and in most cases only small patches of semi-adherent false membrane remained. In the case which survived longest of all, ten days, the innermost lining of the trachea was made up of a very definite layer of granulation tissue, with great formation of new capillary blood-vessels. This gave to the inside of the trachea, when seen at autopsy, a uniform bright red colour over a considerable area near the bifurcation.

The liver presented changes in two cases only, where there was quite definite necrosis of cells in a narrow zone round the hepatic vein, the central vein of the lobules. In most instances no microscopic lesion was to be found. The spleen showed no microscopic changes of importance.

In most of the cases little could be discovered in sections of the kidneys except great congestion of all the renal capillaries, including those of the glomeruli, and cloudy swelling of the cells of the tubular epithelium. In one case, however, which survived only about four days, a very marked hæmorrhagic nephritis was present. Microscopically the renal tissue was intensely congested, and in addition considerable actual hæmorrhage was visible both in the glomerular capsules and in the convoluted tubules. In the glomerular capsules and first convoluted tubules the red corpuscles were well stained, while in the second convoluted tubules the blood corpuscles were inspissated to form casts, and stained a brownish-yellow colour with eosin. The epithelial cells lining the tubules showed desquamation and degenerative change, nuclear staining being lost in many cells. No condition at all resembling this was found in any of the other kidneys examined histologically.

In several of the later cases minute hæmorrhages were found in the brain, but were never numerous. In one case only were hæmorrhages found of the ring shape often so characteristic of some cases of phosgene poisoning. The possibility that a mixture of phosgene and of dichlor-ethyl-sulphide had been inhaled could not be excluded, as no history of the exposure was available.

In reviewing the preceding evidence it appears that the renal pathology is one of the most debatable problems, for on its interpretation largely depends the question of a systemic as compared with a local poisoning. British opinion was rather at variance with French on the matter, the latter maintaining that renal changes, both clinical and *post-mortem*, were frequent, whereas British experience was the reverse. Wilson and Mackintosh lay emphasis on their negative findings in 18 *post-mortem* examinations, supported by reports on the sections by Captain Dunn. " In nearly all the cases, 15 out of 18, there was marked acute congestion, especially of the glomeruli. This had no special significance as it was almost always present with other gases. In three he found a condition of acute hæmorrhagic nephritis with tubular changes. In all three the renal condition was associated with extensive and septic burns. One of these cases showed clearly that a condition of hæmorrhagic nephritis might arise in the complete absence of pulmonary involvement, the sequel only to septic skin burns." The protocol of the case states that " there was no cough, no conjunctivitis, no evidence then or subsequently, before or after death, that the gas had been inhaled." These observers further state: " In the three examples of acute hæmorrhagic nephritis that our *post-mortem* records provide, septic burns overshadowed the other results of gassing ; our clinical material, too, strengthened the opinion that, with the exception of a slight albuminuria seen in a few cases, the expression of a passing congestion, the renal changes, when there are any, are due to burns which have not been treated as wounds or unsuccessfully so treated." The experimental investigations subsequently carried out in the United States fully confirmed the British view that renal changes were very uncommon.

Clinical Features.

After exposure either to the vapour or to a finely atomized spray of the substance, no effects are noticed at first, and the only perceptible evidence that mustard gas is present may be the faint smell. This may be masked by the fumes of high explosives bursting simultaneously and the noise of the latter may also drown the very slight burst of the gas shell, the explosion of which may be hardly noticeable.

After the lapse of two or three hours symptoms begin to appear and subsequently develop with some rapidity. The first symptom of which casualties usually complain is a smarting and watering of the eyes, and irritation soon develops into a definite conjunctivitis, which is both painful and obvious. About this time, also, running from the nose begins, the mucous membrane secreting a thin mucus comparable to the discharge in the early stages of an acute cold. This is accompanied by frequent attacks of repeated sneezing. In chlorarsine poisoning the sneezing is a marked and very early feature after exposure to these compounds, whereas in cases of mustard gassing it only appears after the conjunctivitis and the rhinitis have developed. At about the same time nausea accompanied by retching, vomiting and a certain amount of epigastric pain frequently occur.

The development of symptoms now proceeds rapidly, the conjunctivitis increasing in intensity, the mucous membrane of both palpebral and orbital conjunctiva becoming deeply injected and œdematous, so that gradually the eyelids swell until the palpebral fissure is completely closed. The irritation of the respiratory tract becomes more obvious. The voice gradually becomes harsh, as the swelling of the laryngeal structures increases, and finally a complete aphonia develops when the swelling of the arytenoids is so great as to immobilize the vocal cords. The laryngeal irritation leads to frequent bouts of harsh, dry coughing, which are unaccompanied by any expectoration. The throat feels dry and a sensation of burning is complained of, leading to a desire to drink frequently.

At the same time the effects on the skin become apparent. An erythematous blush spreads and deepens in intensity until the areas affected look as if they had been scorched. The parts most affected are, naturally, those exposed without any clothing, such as the face and the hands; but the areas which are moist, the axillae, the groins, the genitalia and the inner aspect of the thighs also suffer severely, and, should any part of the clothing have been actually splashed by the liquid, the underlying skin will be profoundly irritated. It was a matter for considerable discussion whether this burning of the moist areas was not due to the influence of the secretion of sebum which, by acting as a rapid solvent of the mustard gas, allowed it to penetrate more deeply into the tissues, rather than to the effect of moisture itself.

The scorched and affected skin soon begins to be covered with vesicles which quickly coalesce and form large blisters. At the end of twenty-four hours a typical appearance is presented. The eyes are now completely closed and tears or muco-pus are frequently trickling down the cheeks. The pain in the eyes is intense and leads to constant restlessness. Associated with this local pain there is frequently somewhat severe frontal headache due to the frontal sinuses having been irritated by the nasal inflammation. Photophobia and blepharospasm are extreme, and any attempt to open the eyes for examination or for treatment causes considerable pain. From the nose pours a considerable discharge, which runs over the burnt and excoriated face and increases the irritation. Happily, at this stage, beyond the pain in the eyes and the headache, patients are singularly free from actual suffering, for the burns at this time are practically painless.

In the next twenty-four hours the condition is aggravated by the formation of large blisters and œdema of the lax subcutaneous tissues, so that the ears may become enormously swollen, and the genitalia are almost always affected. The stress of symptoms now falls on the respiratory tract, for the bronchial irritation passes on into a condition of acute bronchitis, associated with the expectoration of much muco-pus and occasionally shreds of necrosed mucous membrane which have separated off from the air passages. Occasionally, instead of these shreds, large masses of mucous membrane, or even complete casts of the bronchi, may be coughed up, and sometimes a death has occurred from the mechanical blocking of the larynx by such a slough. Naturally the temperature, pulse-rate and respiratory rate begin to rise, and the classical signs of an acute septic broncho-pneumonia rapidly develop.

It is this complication which is responsible for the majority of fatalities, and the highest death-rate occurs at the end of the third or fourth day after exposure.* Death within the first twenty-four hours is extremely uncommon unless the patient has been overwhelmed by such a large dose, probably of the actual liquid, that sloughing of the larynx and upper air passages leads to rapid death from asphyxia.

In the later stages the case usually resolves itself into one of two conditions, a spreading septic broncho-pneumonia or, if the skin has been widely affected, a condition of suppurating burns. These two conditions, which, of course, may occur simultaneously, will be dealt with more fully later on.

The following graphic account of the experiences of Major Peyron, of the French Army, who exposed himself to a low concentration of mustard gas in a chamber in order to ascertain at first hand the efficiency of the existing respirator as a protection to the eyes and lungs, is of great interest :—

> The experiment took place on 23rd July, 1917, at Hesdin, in a chamber of 20 cubic meters capacity into which 20 cub. cm. of dichlor-ethyl-sulphide were vaporized.
>
> Peyron entered the chamber at 5.35 p.m., wearing a French mask, type M2, to protect the respiratory tract, head bare, forearms bare, and the right forearm covered with vaseline and lanoline. After fourteen minutes he left the chamber. For the next two or three hours there was no discomfort of any sort. After four hours there were a pricking sensation and cutaneous heat, with reddening of the skin over the bare areas that had been exposed to gas ; also vague sensation of discomfort, with weakness of the legs and giddy sensations.
>
> After five hours nausea developed rapidly and was followed by vomiting. Peyron had eaten dinner an hour and a half after exposure to gas.
>
> During the night the vomiting was frequent, every five minutes, painful, but never copious. The vomiting ceased at the twelfth hour. Peyron felt too ill to observe his skin sensations.

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* See Chart I, Chapter XII, p. 395.

On 24th July no symptoms appeared in the conjunctiva or respiratory tract. Intense erythema with vesicles occurred on the exposed skin, including the hairy scalp, worst on the arm that had been covered with lanoline; to a less extent in the protected axillæ and over the thighs. The penis was œdematous and deformed with blisters covering it and the scrotum.

On 25th July there was slight pricking in the conjunctiva; no chest symptoms, and no albumen. The right forearm was severely blistered, and also the palm of the left hand that had been used to spread the lanoline. The temperature was 38·2° C. in axilla.

On 26th July there was insomnia with sensation of intense heat on the skin; deep erythema over the body, except under the garters and the strap of the wrist watch. The back of the hands showed a brown tint. There was bilateral œdema of the parotid region giving the appearance of mumps, and there was pricking in the nose and throat, but no conjunctivitis or trouble in the respiratory tract. The eyes had been repeatedly washed with bicarbonate of soda.

On 27th July the blisters on the hairy scalp were commencing to dry and form crusts. The scrotum was very œdematous and painful, the penis becoming ulcerated with secondary infections. Small sudaminal vesicles were appearing on the outside of the thighs.

On 28th July the œdema of the face had disappeared, large brownish flakes breaking away from the face and neck. There were very painful prickings in the eyes, which yielded at once to lavage with bicarbonate of soda; similarly with the throat.

Subsequently there was great pain from secondary infections of the ulcerated areas in the perineum and axillæ. Peyron was moved to Compiègne, which he reached on 16th August, for treatment with ambrine. The diffuse erythema had then disappeared, leaving a brown pigmentation over all the body. Secondary infections were still very severe, but the treatment with ambrine at once allayed the pain.

There had never been any bronchitis, laryngitis, or conjunctivitis, and digestion was perfect.

On 25th September there was still a persistent brown staining, which, on 25th October, had almost completely disappeared by a process of desquamation.

Effects on Individual Organs and Tissues.

The Eyes.—Conjunctivitis of an intensity sufficient to incapacitate a man may develop in from two to forty-eight hours after exposure. The onset may be delayed for a very long period, and is then probably due rather to the cumulative effect of minute doses than to one single exposure. Men, for instance, who have been living in contaminated dugouts for a long time, and who have occasionally been forced to remove their masks, will on each such exposure receive a minute dose which ultimately will be sufficient to cause effects. This condition was frequently observed in factories, where the workmen were exposed at times to an atmosphere which was contaminated from leaks in the apparatus.

In the factories it was, therefore, found necessary to instal facilities for frequent lavage of the eyes. The method employed in the French factories proved highly successful. The installation consisted of a long pipe connected with a low-pressure steam exhaust (3 kilos per square centimetre), from which were taken off many leads, each controlled by a tap and terminating in a fine nozzle. Each nozzle was adjusted over a finely drawn-out tube dipping into a 10 per cent. solution of bicarbonate of soda on the principle of the ordinary atomizer. By turning on the tap a finely divided steam spray charged with alkali could be directed into the eyes. Even in the absence of any symptoms the workers were encouraged to employ this treatment as a precaution.

When it is realized that a concentration of one in ten million is sufficient to produce definite pathological changes, it will be seen that a very minute quantity of the fluid leaking from a faulty joint, or carried into a dugout on a boot, the wearer of which has crossed an infected tract of ground, may ultimately produce an effect.

Once the conjunctivitis has made its appearance, it commonly develops with great rapidity. The warning symptom of pricking and irritation of the eyes is soon followed by profuse lachrymation, which is accompanied by pain and headache. Swelling very rapidly supervenes, and may be so extreme as to close completely the palpebral fissure. Such severity naturally is accompanied by very considerable pain and much blepharospasm. The conjunctiva at this stage is swollen, œdematous, and bright red from injection of the blood-vessels.

The photophobia is extreme, and this makes examination difficult, but it is essential to maintain a careful watch on the cornea in order to make certain that serious complications are not ensuing.

The simple lachrymation seen at first quickly becomes muco-purulent, as a result of secondary infection. Provided the case runs a simple course, the conjunctivitis tends to clear quickly, and the injection of blood-vessels commonly disappears in less than a month. In cases, however, where the cornea itself has been severely burnt, the appearance after the early stages is different from that described above. In such cases a dead white band crosses the exposed area of the conjunctiva, whilst the areas protected by the lids show the common injection and œdema. In other words, that part of the eyeball which has not been protected by the lids has been severely burnt, with the result that an area of coagulated œdema develops, compressing the vessels, impairing the circulation, and threatening the nutrition of the cornea. This œdematous band stands out in sharp contrast to the injected appearance of the remainder of the conjunctiva. It is usually not so swollen as the latter, which may bulge out between the lids and obscure the coagulated area. The cornea itself in the affected portion is grey, hazy, and lustreless, and exhibits a blurred corneal reflection and a typical "orange-skinned" surface. The haziness gradually fades off both above and below in the region of that part of the cornea protected by the lids.

The general conjunctival œdema slowly subsides, but the characteristic white band is retained for a long time Slowly, however, the solid œdema is absorbed and the corneal epithelium begins to regain its lustre, and finally a condition is produced which is the exact opposite of the original appearance, that is to say, the inter-palpebral area previously a dead white is now once more vascular and goes through a period of injection whilst the previously injected protected areas are regaining their normal white tint.*

It is only where such complications as corneal ulceration leading to permanent nebulæ, or severe burning resulting in adhesions between the palpebral and ocular conjunctiva occur, that permanent after-effects are met with in the eyes, and these are relatively rare.

The ophthalmic specialists reported from a very wide experience of gassed eyes during the war that the eye injuries fell into three main groups :—

(1) The milder cases, forming 75 per cent. of the total, which recovered to be fit for duty so far as the eyes were concerned, in from one to four weeks, on an average about two weeks.

(2) Intermediate cases, about 15 per cent., which recovered in from four to six weeks.

(3) Severe cases with corneal changes, about 10 per cent., which needed from two to four months for recovery.

Actually, there were only ten cases seen with persistent impairment of vision, and only four cases of panophthalmitis requiring removal of the eye.

The Respiratory Tract.—The nasal mucous membrane becomes very inflamed and discharges a profuse watery secretion which later develops into muco-pus, and may be accompanied by sloughs. The course is much the same as that followed by a common cold, only more severe, and is produced by the action of the ordinary bacteria of the nasal passages which flourish in the damaged membrane. This is a typical example of the method by which mustard gas causes its effects, for the injured tissues are invaded by the common organisms present in the region attacked. Given a suitable pabulum, they multiply and set up their characteristic manifestations. The copious secretion running from the nose acts as an irritant to the anterior nares, which may become very sore and encrusted. Epistaxis and ulceration are rare.

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* Details of the progressive lesions in the cornea and conjunctivæ are given, with full illustrations, in Vol. II of the Surgery of the War, Chapter XV.

The posterior pharyngeal wall shares in the general inflammation and may be eroded, when pain on swallowing will be a pronounced symptom.

The larynx is very commonly affected, and even where no subsequent bronchitis develops, hoarseness and aphonia are frequently complained of. Exposure to a very low concentration for prolonged or frequent periods leads to a mild laryngitis. This was often noticeable in officers who were obliged, in giving orders, to remove the face-piece of their masks. Ordinarily the laryngeal symptoms appear within a few hours of exposure, almost simultaneously with the conjunctivitis. The irritability of the larynx leads to a husky cough, at first unaccompanied by expectoration. Superficial ulceration of the vocal cords has occasionally been noted. More frequently in the severer cases there is a yellow fibrinous slough on the true vocal cords, and after this slough has vanished there is often some slight residual œdema and a partial weakness of one or other of the laryngeal muscles, so that the recovery of the voice is correspondingly delayed.

In the great majority of cases all laryngeal symptoms disappear within a fortnight, and a persistence beyond this period, except in the rare ulcerative cases, should arouse suspicion of a functional condition having supervened.

From the point of view of mortality and of serious and lasting after-effects, it is the injury to the trachea and the lungs that is the most important feature of mustard gas poisoning. The laryngeal inflammation indicated by the huskiness and irritable cough tends to be reproduced in a similar inflammation of the trachea and bronchi. Pain behind the sternum, increasing cough and the signs of developing temperature and rising pulse indicate the onset of a severe bronchitis which may progress into broncho-pneumonia. The dry irritating cough complained of at first is replaced by a loose cough accompanied by profuse expectoration. This is at first thick and mucopurulent, but tends in the protracted cases to become thin and watery. The broncho-pneumonia and septic bronchitis following gassing present no features which are new in medical literature. Abscess formation, pleurisy, bronchiectasis, patchy collapse, and compensatory emphysema, and very occasionally actual gangrene of lung, have all been noted as a result of the initial bronchitis.

It is well to emphasize here once again that the effects are the result not of the actual gassing but of the secondary bacterial invasion which follows thereon. It must not be imagined, however, that broncho-pneumonia is an extremely frequent complication. Happily, in the great majority of the cases where the respiratory tract has been involved, the lesion is confined to a bronchitis which clears up in the course of a month or six weeks. In these cases permanent after effects are not likely to occur. In cases where severe broncho-pneumonia has developed, lasting ill-effects may naturally be experienced. The pulmonary infection may be followed by fibrosis, particularly of the peri-bronchial type, by permanent pleural

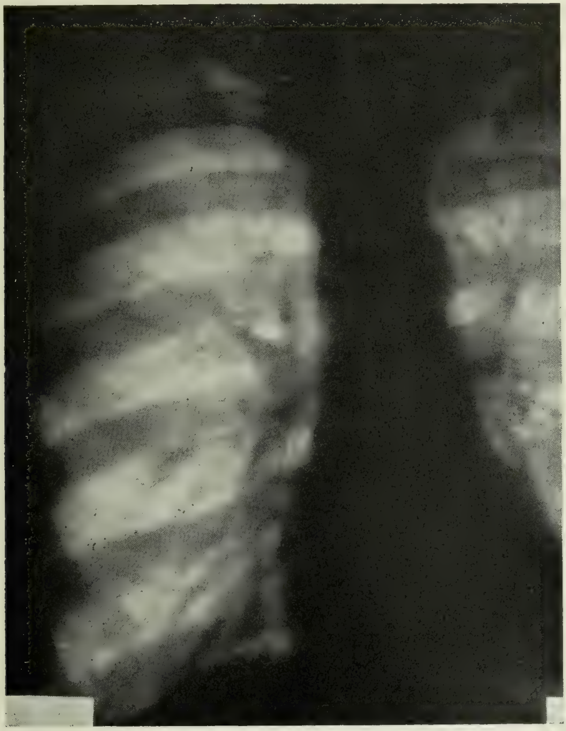


Fig. 3.—Fibrosis of the lungs resulting from mustard gas poisoning.

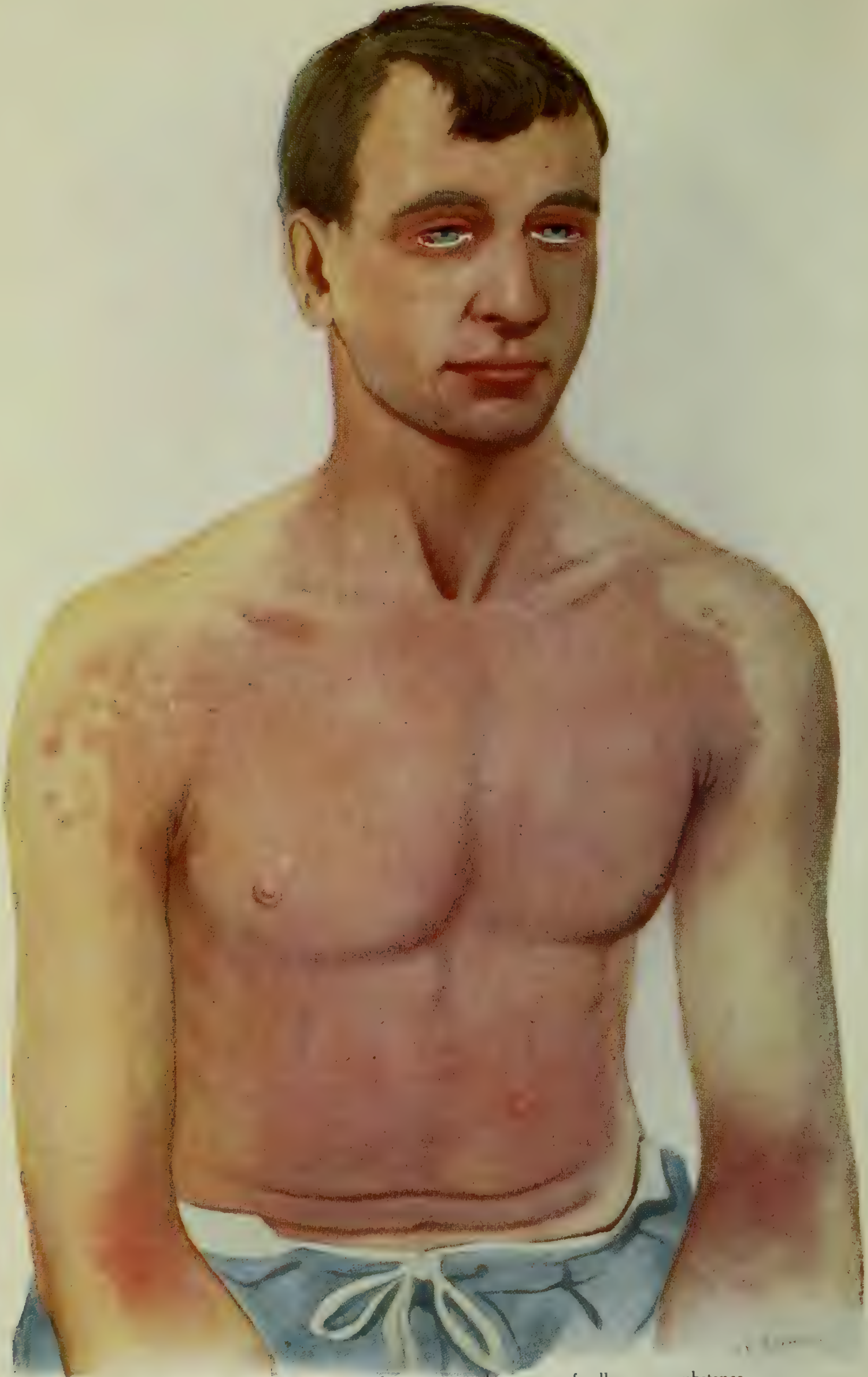
adhesions, and occasionally by a diffuse pulmonary fibrosis from failure of resolution of the generalized broncho-pneumonia. Fig. 3 illustrates the very extensive interlobular fibrosis, extending through both lungs, which may follow exposure to mustard gas. The man was gassed in November 1917, and was in hospital for nine months, suffering from "tightness on the chest" and some cough. At the time of the X-ray examination in May 1922 he still complained of the same symptoms, and, though clinical examination did not indicate much, skiagraphy showed this very extensive and permanent lesion of the lungs.

Alimentary Tract.—Vomiting is an early and frequent symptom and is due to the swallowing of saliva or nasal secretion which has been infected by mustard gas. Actual trauma to the gastric mucous membrane is, however, very uncommon, and only rarely has hæmatemesis been described. The vomiting is accompanied by much epigastric pain, but this disappears almost as soon as the vomiting and neither condition commonly persists more than forty-eight hours. On the other hand, though organic lesions have not been met with, a functional condition of vomiting persisting for prolonged periods is not uncommon. Cases have been seen in which such vomiting has lasted for three years, largely owing to the fact that the functional element had not been recognized. In no case of gassing in the field was there any evidence of an enteritis, and in those cases in which diarrhœa did occur it was manifest that this was due not to gassing, but to some other associated cause.

The Kidneys.—It has already been pointed out that in the early stages renal manifestations are uncommon. An occasional trace of albumen may be found in the urine during the first twenty-four hours, principally in cases where a fatal issue follows quickly. Such albuminuria is almost certainly a result of congestion from circulatory weakness, and not in any way due to the action of the gas on the kidneys. It is only in the late stages, and particularly in those cases where widespread septic burns have occurred that renal complications have been noticed. A condition of acute hæmorrhagic nephritis may then arise. Here again the fatality is the result of a secondary affection and not of the initial gassing.

As a result of œdema and vesication of the penis from burns, painful micturition and even retention of urine may be met with occasionally. The British records contain no note of any actual lesions in the bladder.

PLATE VI.



Erythema skin from general exposure to the vapour of yellow cross substance.

History of case :— Exposed to "Mustard Gas" at Ypres on 12th July, 1917, when this substance was first employed by the enemy. Drawing made on the 5th day. The laryngitis and bronchitis were slight, so that the poisonous vapour must have acted only in low concentration. But the reddening of the skin was fairly intense because the man had been sweating freely when exposed to the gas, and he was not washed afterwards, nor was his clothing changed. The erythema was succeeded by staining in the same areas of the skin.

Circulatory System.—Results of various observations on the hæmoglobin blood content and cellular changes in the blood have been referred to elsewhere. Blood changes are not met with, and the alteration in leucocytic counts is due either to pneumonic complications or to sepsis in skin burns. The remarkable blood concentration seen in the lung irritant class is not met with in mustard gassing.

As regards the cardiac mechanism, primary changes have not been described. The heart may and does share in the general toxæmia of pneumonia or sepsis, but otherwise organic changes have not been met with.

The functional condition of disordered action of the heart or " effort syndrome " is, as might be expected, a not uncommon sequela of gassing.

The Skin.—Next in importance to its effect on the lungs, from the point of view of morbidity, of invalidity, and of total numbers, is the effect of mustard gas on the skin. In fact, as protection from masks became better the problem of the skin began to bulk more largely, for, however perfectly a mask could protect its wearer from both eye and respiratory troubles, it was useless in preventing burning of the skin.

Protective clothing was no solution of the problem, and where ground was contaminated troops could only be moved at grave risk of sustaining burns. Either the vapour or the actual liquid is capable of inflicting burns on the skin, and any object which has been contaminated by the fluid is also a possible source of burning. Where direct splashing has taken place, an immediate burn will naturally follow ; where there has been exposure only to the vapour the burning is mainly confined to the exposed surfaces and to those skin areas which are either constantly moist or are well supplied with sebaceous glands. The skin of the forearm, for instance, is several times more resistant than the skin of the ante-cubital fossa.

The first sign of burning is a diffuse erythema, which appears within from two to forty-eight hours after exposure and tends to spread rapidly (Plate VI). It is not unlike the eruption of scarlet fever, and has, indeed, on occasion been mistaken for this infection. At this time no pain and only a very slight degree of irritation is experienced.

In the next stage superficial blistering appears on the erythematous areas, usually at first as small vesicles, which ultimately coalesce into large blebs. When pricked these blebs are found to contain a clear serum, and if the raised-up epithelium be removed a raw, red, weeping surface is left.

Even at this stage, pain is very slight and it is only when secondary infection is superimposed that the condition becomes severe and the pain a serious trouble (Plate VII).

Rarely, blisters have appeared in crops as long as a week after the first exposure, and it is difficult to account for this, as it has been seen in patients who have been stripped of their clothing at an early stage and carefully washed.

In the third stage a pigmentary change is the most marked feature. The skin develops a purple or brown or even almost black tint, and most commonly this staining is seen in the areas which were previously erythematous. It does not, however, always follow erythema, for pigmentation has been seen where no previous redness was noticed. The pigmentation is confined to the epithelial layers and does not affect the true corium, for it can be removed by rubbing off the pigmented epithelium and it invariably disappears in the course of three or four weeks.

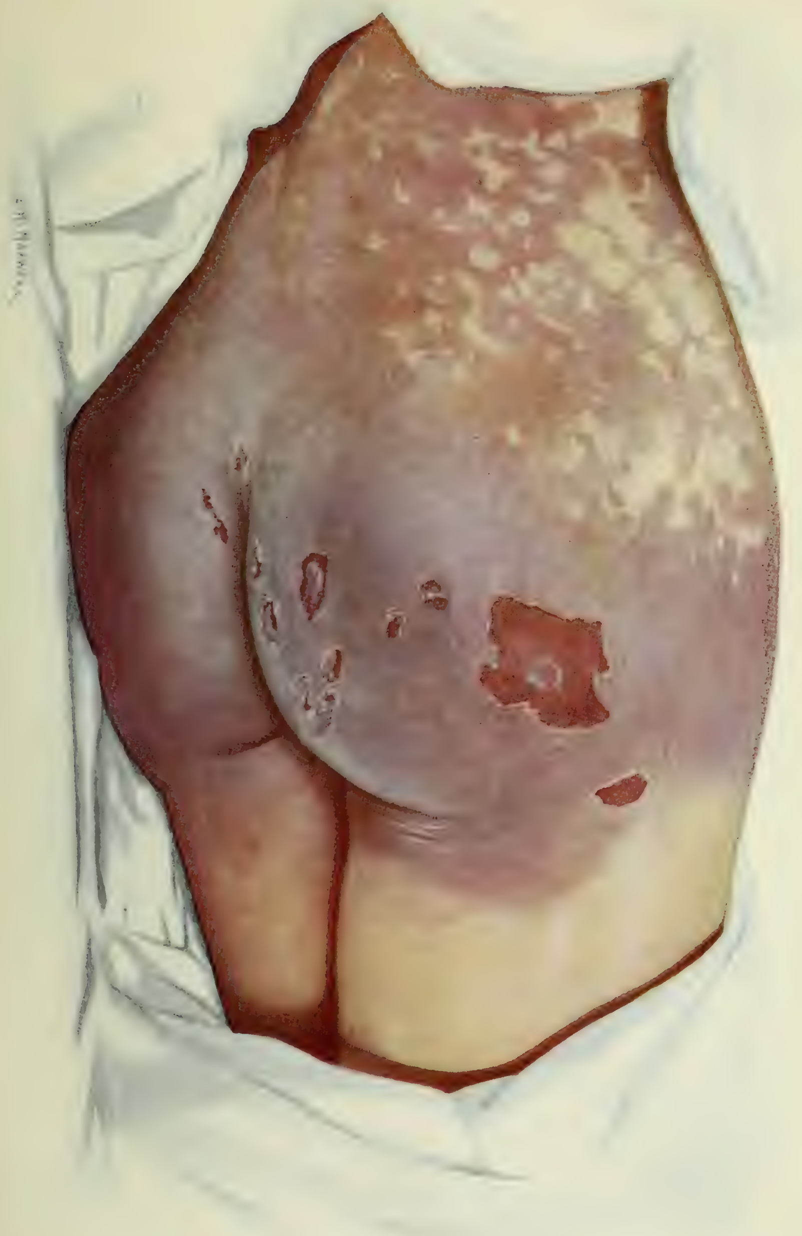
This is the typical course followed by an uncomplicated case of burns. It is only when sepsis gains a hold on the tissues damaged by mustard gas that serious consequences result. Should such occur, the course followed is somewhat similar to that of a burn from any thermal cause, with sloughing and necrosis of superficial tissues, and the slow healing of a raw, granulating area. But the recovery in all serious instances of skin destruction, whether septic or relatively clean, is slow in comparison with a skin lesion from ordinary mechanical accidents, because the chemical irritant damages the vitality of the tissues surrounding the area of actual destruction and all the processes of repair are correspondingly delayed.

As curiosities in the way of results from burns may be mentioned such conditions as destruction of the membrana tympani from actual splashing with the fluid, and permanent baldness from destruction of hair-follicles. An occasional but very intractable after-effect of burns is a condition of furunculosis, crops of boils appearing not only on the previously affected areas, but over the whole trunk and limbs.

Individual Susceptibility.

There is considerable variation in the susceptibility of individuals to the cutaneous effect of mustard gas. Lynch, Smith and Marshall, a group of American workers, have recorded the results of an experimental investigation on this point. Some individuals showed a burn after an exposure of

PLATE VII.



Blistering of buttocks by mustard gas.

History of case;— The man sat down on ground that was contaminated by the poison, and the vapour passed through his clothing causing inflammation of the buttocks and of the scrotum. A diffuse reddening appeared twenty-four hours after exposure, and this was followed by an outcrop of superficial blisters. On the eighth day the erythema began to be replaced by a brown staining, and the drawing was made on the eleventh day during this change of tints. Infection of the raw surface was avoided, and the healing was complete in three weeks.

five seconds to air saturated with the vapour, others showed none after an exposure of five minutes. About 20 per cent. gave no burn from an application of a 1 per cent. solution, and were the resistant class. About 2 per cent. gave a severe burn with blistering from a 1 per cent. solution, and a definite burn from even a 0·01 per cent. solution. These were the hyper-sensitive class. It is interesting to note that of negroes 78 per cent. belonged to the resistant class. This suggests that resistance is in part a racial characteristic.*

The hyper-sensitive will certainly become casualties if exposed to a minimal dose, and steps should be taken to eliminate such men from fighting troops and also from the personnel of factories engaged in manufacturing mustard gas.

These American investigators recommended a wholesale test for sensitivity. This practically consists in streaking the skin of the forearm with very fine glass rods moistened with a 1 or 0·01 per cent. solution of mustard gas in paraffin. The affected skin is examined after twenty-four hours. The very sensitive react to the 0·01 per cent. and should be eliminated from possibility of exposure.

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* Some important details with regard to poisoning by mustard gas have been obtained from a report by Mr. R. P. Whitelaw, who was superintendent of a large factory under the Ministry of Munitions, established at Avonmouth from 15th June, 1918, onwards. Mr. Whitelaw had a staff of 1,100, nearly all of whom suffered over and over again from gas poisoning.

The lesions caused by contact with the gas were blisters of the dorsum of the hands, scalp, shoulder, abdomen, arm, buttock, genitals, thighs, legs and feet; in fact the only place where blisters were not seen was in the palms of the hands.

Inhalation of the gas caused pharyngitis, tracheitis, broncho-pneumonia, and conjunctivitis. These were followed in many cases by the chronic symptoms of debility, gastric pain, mental inertia, breathlessness, errors in refraction, and amnesia.

The chief measure of protection to the worker consisted of a very elaborate and adequate system of ventilation, which conveyed the fumes by a powerful suction draught through layers of coke and finally to a drain running a considerable distance from the plant. Respirators and suits of overalls were issued to all workers.

There was a first aid hut, and the hospital, consisting of 30 beds, and maintained in connection with the factory, was staffed by one medical officer, two trained nursing sisters and six partially trained probationers.

Practically every man on the staff was more or less severely gassed during the few months the factory was in operation, and many were admitted for treatment several times. The heroism and fortitude which they displayed bear comparison with any deed of bravery on the battle-front. The injured returned to work again and again, notwithstanding burns, sores and ill-health, being determined at all costs to themselves to produce the amount of gas required to counter-attack the enemy who had first undertaken this form of gas offensive in July 1917.

There is some evidence that sensitivity may be enhanced in the individual as the result of previous exposure. Old burns are more vulnerable on fresh exposure than undamaged skin.

It has been repeatedly stated that no adequate proof had been obtained that mustard gas acts other than locally or can produce any systematic effect. In the French mustard gas factories, however, it was noticed that continuous work engendered a falling off in general health. It was found advisable, therefore, that workers should have two days off each week, and rest hostels at a high altitude were established in country places for them.

This experience must not be taken as a proof of any systematic action of the poison. The failure in health may equally have been due to hard work on a scanty ration, or to defective ventilation leading to local irritation so slight as to be barely noticeable, but yet sufficient to impair health.

Frequent medical inspection, ample bathing facilities, and the most perfect ventilating system possible were the methods employed in British factories to maintain the health of the personnel.*

Treatment.

The first essential of treatment is to aim at preventing further infection from contaminated clothing which, slowly giving off the vapour of mustard gas, may lead to additional lesions. It is therefore necessary to arrange for the removal of all the outer clothing at as early a stage as possible and, should this clothing have been in any way grossly contaminated, to strip the patient entirely. The next procedure is to wash the whole of the skin thoroughly, employing plenty of water and either a sufficiency of soft soap or a weak alkaline solution, which helps to neutralize any of the poison left on the body.

The second essential is a twofold one : (*a*) to relieve immediate symptoms, (*b*) to prevent septic after-effects. It has already been pointed out that mustard gas kills not by its immediate direct action, but owing to the fact that the inflammation it causes opens the door to a secondary invasion by the organisms which are common to the area affected. The question of treatment will, therefore, be best dealt with by taking in succession the various parts affected.

The Eyes.—Pain is the symptom most complained of, but it should not be treated by the use of cocaine. This drug gives temporary relief, but it tends to loosen the corneal epithelium, the very condition which should be avoided, and therefore at the most one instillation only of cocaine should be given if the pain is intense. For the majority of cases, in which eye symptoms are not severe, the best treatment is frequent gentle bathing, employing some bland preparation such as boracic acid, normal saline, or 2 per cent. solution of sodium bicarbonate. Where many cases are being dealt with, one of these solutions should be kept available in bulk, the treatment being carried out by orderlies furnished with pint bottles of the warmed solution provided with suitable dropping nozzles. In order to prevent the eyelids becoming glued together by secretions, a few drops of liquid paraffin should be dropped into the eyes three times a day. Shades made of brown paper should be provided for all cases where photophobia is considerable, but the practice of bandaging the eyes should not be followed, as it tends to keep the eyelids closed and prevent free drainage of secretion. In the severe cases, where accompanied by marked blepharospasm and continued pain, the essential treatment is to employ atropine, using a 1 per cent. ointment. This should be repeated as necessary every twelve hours, and in that way much of the pain and spasm arising from reflex irritation of the iris and ciliary body is relieved. In all cases where the cornea is affected, this systematic use of atropine should be persisted in, in order to keep the pupil well dilated until the cornea has become quite smooth.

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* Report No. 18, Chemical Warfare Medical Committee, by Shufflebotham.

In the later stages, when the discharge tends to become mucopurulent, a mild antiseptic should be employed, and a weak solution of argyrol or protargol instilled twice a day will be found helpful and efficient. This treatment with an antiseptic lotion is of particular importance whenever the cornea is grey and roughened, for otherwise the damaged epithelium may be penetrated by infective organisms and infiltrating ulceration result. Should, unfortunately, ulceration occur, the treatment already outlined should be persevered with, cleansing the conjunctival sac by frequent gentle bathing, and relieving pain by hot applications over the closed lids four times a day.*

So soon as the acute stage, whether in the mild or the severe case, is passed, and the swelling of the conjunctiva has subsided, the use of atropine should be dispensed with and an astringent lotion should be instilled three times a day. The following formula has been found very effective :—

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* Further details of treatment for severer cases of ulceration and infection are given in the chapter on Injuries and Affections of the Eye, in Vol. II of the Surgery of the War, Chapter XV.

Boric acid	gr. 10.
Zinc sulphate	,, 1–2.
Adrenalin (1 in 1,000 solution)	drachm ½–1.
Water	to the ounce.

So soon as the pupil has regained its normal size the shade and dark glasses should be removed, for a persistence in the use of such protection tends to foster functional photophobia. General tonic treatment with exercise and new interests will quickly restore a man to his normal balance.

Should photophobia and lachrymation persist apart from evidence of any lasting lesion in the eyes, blistering of the temples on alternate days and douching the eyes with very cold water twice a day will be found of value.

The functional photophobia and blepharospasm are best treated on these lines, but the whole environment of the patient must be considered and a convalescent camp where both physical and mental interests and occupations are provided will be the best agency to counteract functional tendency.

The Nose.—The irritation of the mucous membrane in the early stages rarely calls for treatment because this condition is usually overshadowed by that in the eyes. Should there be pain and distressing discharge, a 5 per cent. solution of bi-carbonate of soda may be employed as a nasal douche. In rare cases where a persistent muco-purulent discharge, associated with ulceration and occasionally with epistaxis, is long continued, an astringent lotion should be employed, one containing 1 to 2 gr. of zinc sulphate with boric acid being helpful.

The Larynx.—Laryngeal irritation or inflammation is best dealt with by topical treatment, such as laryngeal spraying with paroleine, or by inhalations of menthol, according to the following formula : Menthol gr. 10 in tinct. benzoin co. 1 oz. Add one teaspoonful to a pint of boiling water and inhale the steam. In the French armies great use was made of *huile gomenolée,* 1 or 2 c.c. of this oil suitably warmed being injected daily into the larynx by means of a curved laryngeal syringe. This oil was also employed in acute suffocative cases where blocking below the larynx by sloughs or membranes was causing acute dyspnœa. In these cases it was injected into the trachea by means of a fine needle inserted through the cricothyroid membrane twice a day.

The functional aphonia which is a frequent after-effect in mustard gassing may be dealt with either by re-education of speech, as was done for the mutism of shell-shock, or by direct faradization of the vocal cords, with blistering of the skin over the larynx. This treatment, combined with the stimulating environment already described in connection with photophobia, is sufficient to obtain a complete cure in the vast majority of cases.

The Lungs.—As the infections of the respiratory tract are those which cause the great majority of fatal issues, treatment should be directed towards limiting or combating the bacterial infection of the bronchi. There is, unhappily, no specific which can be relied on to effect this. A certain value attaches, however, to the routine employment of volatile antiseptics from the earliest possible stage. If for no other reason than that relief is obtained from the harassing cough their use is of value. Whilst no statistics are available in proof of the argument, the consensus of opinion amongst medical officers in casualty clearing stations was that broncho-pneumonia was less prevalent and less virulent where such a procedure had been adopted on a wholesale scale. In the Fifth Army this method was given a wide trial, on the suggestion of Captain Ramsay, R.A.M.C., No. 64 Casualty Clearing Station, who devised a mask of perforated zinc made from the sheeting supplied for splinting. This was cut into sections of butterfly shape, which by bending could be fashioned to form an inhaler similar to the well-known Burney Yeo inhaler, the cut edges being guarded by Mead's strapping. The formula which was generally employed was as follows :—

Menthol	gr. 20.
Chloroform	min. 60.
Creosote	,, 60.
Ol. eucalypti	,, 20.
Tinct. iodine	,, 30.
Sp. vini rect.	to one ounce.

A few drops of this were placed hourly on a pad of lint in the mask. The menthol in the solution certainly alleviated the harsh, dry cough, and it was thought that the antiseptics had some retarding influence on the growth of organisms. Menthol was also found extremely useful if given as an inhalant before an anæsthetic was administered to a case of mustard gassing requiring operation for some concomitant wound. In these cases the laryngitis was such that until it had been allayed by inhaling menthol it was found impossible to induce anæsthesia, as the anæsthetic set up paroxysms of coughing by irritating the larynx.

In the later stages where broncho-pneumonia supervenes, treatment must be directed in accordance with recognized symptoms and precedure. It is important to note that venesection is of no value in the early stages of mustard gassing, though occasionally it may be necessary at a later stage where cyanosis and embarrassment of the right heart develop as a result of diffuse broncho-pneumonia. The prophylactic venesection which was found of use in the lung irritant cases and of essential value in the early treatment of the pulmonary œdema has no place in the treatment of mustard gas cases. Medical officers, therefore, must be conversant with the clinical aspects of these two groups of cases if treatment is to be given intelligently, as otherwise unnecessary venesection may be employed.

Oxygen, also, of such enormous value in the case of pulmonary œdema, plays only a small part in the treatment of mustard gassing, and except in the occasional late condition of oxygen want, as the result of grave and widespread pulmonary consolidation, will not be required.

The essence of treatment will be, as in civil practice, the support of the heart by means of all recognized stimulants, and the employment of expectorants where the muco-pus is tenacious and causes difficulty in expulsion.

It is necessary here to refer to a method of treatment which was for a short period employed in the British army under a misapprehension both as to the pathological condition present and the means to deal with this. It was known from experimental evidence that the calcium salts were of value in preventing œdema, and the suggestion that these salts might be usefully employed by subcutaneous injection was made without sufficient recognition of the fact that œdema played a very small part in the pathological sequence of events. Unfortunately, a 10 per cent. solution of calcium chloride was recommended and was for a short period employed in a large number of cases, three injections of 10 to 20 c.c. being given. The treatment had no effect whatever in abating any of the symptoms, but it caused great pain at the site of injection, and led in many cases to a local necrosis of tissue which required a long time for healing.*

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* Experimental investigations were made during the war by the Germans, Laqueur and Magnus, as to the possibility of checking the pulmonary œdema resulting from phosgene poisoning by means of subcutaneous administration of calcium chloride solution, and, so far as experiments on animals were concerned, some benefit was observed. A captured German document, dated 10th September, 1917, actually recommends this method of treatment for gas casualties caused by phosgene in the field, the subcutaneous injection of amounts up to 800 c.c. of a solution containing 1 per cent. of calcium chloride and 0·5 per cent. of sodium chloride being suggested, but it would appear that this practice was soon discontinued owing to the liability to pain and tissue necrosis at the point of injection.

The Skin.—Methods of preventing skin effects by immediate treatment are referred to in the chapter on protective measures against gas attacks. To a limited extent, the immediate application of chloride of lime to the hands when soiled by touching contaminated equipment or weapons does have some protective effect. To a far less extent the application of solid sodium bicarbonate well rubbed in may also minimize, though not entirely prevent, skin lesions. Early experience suggested that the use of ointments or emollients would be helpful and this was tried until it was realized that such treatment, rather than helping, increased the trouble. Mustard gas being soluble in animal fats, any actual drops or vapour of the gas present on the skin would, when the ointment was applied, be absorbed, and so the radius of action become extended and the penetrative effect increased. This remark does not apply to the ointments designed to afford protection to the skin which were produced as the result of research at a later period, and more especially a paste introduced by the Americans of zinc stearate and vegetable oil which certainly had some value as a protective agency, or protective ointments containing chloride of lime or dichloramine-T, which gave promising results in the hands of the British and French investigators.

On the whole, however, it must be expected that once the skin has been definitely contaminated, a lesion will follow and treatment must be directed to minimizing discomfort and especially to preventing septic invasion, for if the burns become septic, convalescence is greatly protracted.

In the stage of erythema, where, beyond the colour changes, nothing is complained of, it is wise to use dusting powder freely, on the understanding that the initial careful and thorough washing of the whole body has already been carried out. A useful formula was found to be equal parts of boric acid, starch, zinc oxide, and chalk. At times a mixture of chloride of lime and chalk was tried, but was not found to have any better effect.

In the next stage, when vesicles and blebs begin to appear and the damaged epithelium tends to strip off and leave an exposed raw surface, precautions against sepsis form the critical test of successful treatment. The blisters as they appear should be emptied with sterile precautions, employing either a syringe to draw off the fluid or a sterile needle to puncture the bleb, after which the fluid may be removed by pressure with a pad of sterile gauze. It is important not to strip off the raised epithelium, as this will make the resulting raw area much more painful.

Small clean burns will be found to heal well if treated with Lassar's paste (zinc oxide 24 parts, starch 24 parts, salicylic acid 2 parts, vaseline 50 parts). This may be applied continuously, provided cleanliness is maintained. At the first sign of sepsis supervening, discomfort or pain being regarded as a danger signal, it is well to clean off the Lassar's paste and apply boracic fomentations.

In areas where it is possible, a continuous bath, soaking the whole affected part in warm and frequently changed boracic lotion, will be found a treatment both soothing and efficacious. A eusol dressing kept damp by a constant drip or a cotton wick feed is also a useful method of treating the septic area, though it may be somewhat painful.

After sepsis has been overcome by one or other of these antiseptic treatments, the final stages of healing may be helped either by Lassar's paste or a mild ointment such as the following:—

Boric acid	gr. 15
Powdered lead acetate	,, 5
Zinc oxide	,, 20
Paraffin	to the ounce.

A dressing of simple paraffin with 5 per cent. carbolic acid may be prepared as an alternative treatment. For small, clean areas, ambrine applied either with a spray or a brush is a useful dressing. It has, however, a tendency to seal up discharges and thus increase sepsis, and therefore, when it is employed, constant attention must be given and if any sign of pyogenic infection appears it should immediately be discontinued and the antiseptic treatment with baths or fomentations instituted. Dichloramine-T is useful when applied in a paste to small areas; it is difficult, however, to watch progress beneath such an application. Picric acid in a 1 per cent. watery solution was a favourite and extensively used treatment, particularly in field ambulance work. Where burns are of the first and second degree only it is a useful and easily applied method of treatment. In late stages ordinary desquamation may be hastened by alkaline baths and the inunction of salicylic acid ointment.

As a result of experience, treatment in the British hospitals was ultimately confined chiefly to the salicylic acid ointment for clean cases and to eusol or boracic fomentations where sepsis appeared.

The treatment generally adopted by the American medical officers was the employment of Dakin's solution, 0·5 per cent.

hypochlorous acid, to the exclusion of all ointments, continuously until healing took place.*

The French tried a variety of methods. For immediate treatment a 4 per cent. solution of potassium permanganate was recommended, in the hope of preventing erythema and blistering. Later on in the progress of the case hydrogen peroxide was found a useful application for relieving pain and cleansing septic areas, and it was applied as a damp dressing renewed every six hours. Another antiseptic treatment which was widely used was the application of *Eau d'Alibour* :—

Sulphate of copper	1 per cent.
Sulphate of zinc	3·5 ,,
Camphor	0·5 ,,
Safran	2 ,, in water.

Diluted to 1 in 5 before use.

This solution, which was antiseptic and promoted healing, was applied by means of a damp dressing, pads of gauze being wrung out in the solution and changed every twelve hours. Owing to the pain it caused, it could not be used on the genitalia, though permissible on all other parts.

Another common line of treatment was by a mild antiseptic greasy application, prepared by soaking four layers of plain gauze in a preparation containing

Paraffin	50 grm.
Vaseline	100 ,,
Carbolic acid	0·25 ,,

wringing nearly dry and changing twice daily.

The use of ambrine was finally discontinued owing to the drawbacks already mentioned.

General Treatment.—In the first few days after exposure a light diet is desirable for all cases. The vomiting, nausea, and epigastric discomfort cause a distaste for solid food, but fluids, especially milk and beef-tea, may be given freely, and patients should also be encouraged to drink water. As convalescence proceeds, a full diet is required, and this should be as varied as possible. The severe cases of pneumonia will naturally be kept on a fever diet, whilst patients with body burns require a generous diet and stimulants.

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* The formula for this solution is as follows: To one litre of water add 12·5 grm. of bleaching powder. Shake vigorously. Add 12·5 grm. of boric acid powder and shake again. Allow to stand overnight and filter. The solution, which contains about 0·54 per cent. of hypochlorous acid, 1·28 per cent. of calcium biborate and 0·17 per cent. of calcium chloride, is now ready for use.

The management of the convalescent period provides the great test for the medical officer's ability, because he is required not only to treat the disease, but to restore moral, to cut short hospitalization, and to lift men out of the slough of self-analysis which so often follows gassing. The best results will therefore be obtained by placing gassed cases in selected hospitals under the care of medical officers with special aptitude for this.

As soon as a man is convalescent and free from the danger of septic complications, he should be discharged from hospital to a convalescent centre, where a well-ordered routine of exercise, employment, amusement, and rest will quickly restore him to a state of physical and mental fitness.

Functional After-effects.

Reference has been made to the onset of a functional or neurasthenic disorder following exposure to mustard gas. The subject is, however, of such great importance from the point of view of wastage and duration of invalidity that it is necessary to consider this aspect in more detail.

Functional disorders fall, in the main, into two classes. In the first, exposure to gas, often to a minimal and barely a toxic concentration, may yet prove the final factor in upsetting a nervous system already breaking down as the result of trench exhaustion, exposure to bombardment, or ill-health caused by some chronic condition such as mild trench fever, and other diseases. In such circumstances it will tend to produce an " anxiety state " similar in all respects to the neurasthenia or shell-shock so common in the war. It is hardly fair, therefore, to regard such a class as being caused very directly by gas, and it would be better to consider the gassing as merely a final incident.

The second class is a far more important one, because in these cases a local but real organic lesion from mustard gas causes certain irritant reflexes, such as coughing or photophobia or vomiting, and these sensory reflexes are perpetuated by introspection, almost in a form of conversion hysteria, long after their organic cause has been cured. It was due to a lack of appreciation of this possibility that much delay took place in returning men to duty.

Functional photophobia and aphonia are responsible for the great majority of the cases. This is hardly surprising when it is realized that the initial trauma had affected a highly organized special sense, and that the fear of blindness or dumbness resulting from the injury may very well have acted to perpetuate the symptoms. That ill-advised and unnecessary treatment was also a probable factor in many cases cannot be denied. The acute conjunctivitis with blepharospasm and photophobia that characterized the early stages of the eye lesion was naturally treated by protecting the eye from light. Eye-shields, either extemporized from brown paper or of very light cotton-wool protective bandages, were almost universally applied at casualty clearing stations, but the fact that they were retained in use long after the necessity had passed was undoubted, and it was not an uncommon thing to see a man, gassed months previously, groping about with eyes half-closed and heavily shielded from the light, when all the actual manifestations of the eye lesion had totally disappeared. There can be no doubt that the suggestive influence of wearing a shade perpetuated the functional manifestation. Similarly, the protective mechanism of blepharospasm, called into action at the time of the injury, was maintained in action by auto-suggestion long after the need for it had disappeared.

The persistent aphonia, accompanied often by a useless harsh cough, was another striking manifestation of auto-suggestion, arising from the initial laryngeal irritation. The characteristic cough was useless. It was either dry or accompanied by watery sputum, mainly of salivary origin ; it was usually much worse at night, and was of a ringing, harsh quality.

The functional aphonia yielded very rapidly to treatment by suggestion and breathing exercises, when the medical officer realized the nature of the condition and gave the patient confidence in his early recovery.

Functional vomiting was not common in 1918, though in 1917 early vomiting had been noted as a symptom of onset in nearly 80 per cent. of the cases. A possible explanation of this is that as time went on the men realized that gas poisoning did not necessarily mean poisoning through the stomach. At the outset, and to the ill-informed, poisoning invariably suggested involvement of the gastro-intestinal tract, and hence functional perpetuation of vomiting would occur. Also there was the fact that mustard gas did not cause any organic lesions in the mucous membrane of the stomach, and therefore sensory reflexes from this organ did not exist long enough to serve as a foundation upon which functional phenomena might later arise.

Of all after-effects, functional or organic, those affecting the heart present the greatest difficulty in assessment. Disordered action of the heart, or "effort syndrome," arose from so many diverse causes that gassing naturally was regarded as one of them. Some observers in home hospitals estimated the incidence at 30 per cent. of all mustard gas cases they saw. Taking 50 per cent. as a working figure to represent the proportion of casualties evacuated to England, this would make the real incidence about 15 per cent. in the total of cases. This in itself is an extremely high figure, and would, if correct, suggest a very serious invalidity. But close statistical analysis of groups of cases both in France and in England, proved that the estimated figure was far too high. The individual estimate probably rested on a careless assumption that because phosgene poisoning had been proved to lead to disordered action of the heart, so a like result might be expected after mustard gas.

In August 1917 the incidence of disordered action of the heart was investigated amongst the 300 casualties treated at Hardelot. Out of the total 300 there were 33 who showed clinical features suggesting the development of disordered action of the heart. From Hardelot these 33 cases were transferred about the seventh week after gassing to the heart-training section at No. 1 Convalescent Depôt, where they were graded by Lieut.-Colonel W. E. Hume and discharged during October to full duty or to lighter work at the base.

The after history for all was obtained in July 1918, that is, rather less than a year after exposure to gas. Seventeen were found fit and 16 unfit or in a lower category, 5 being so classified from other causes than gas. Of the 16 unfits, 7 were evacuated to the United Kingdom and 9 transferred to base or labour corps duties. Of the 11 unfit from the gassing alone, only 4 had disordered action of the heart, 2 had neurasthenia, 1 had gastritis, and the cause of unfitness in 4 was unknown.

The total results proved that little more than 10 per cent. of the 300 casualties had shown phenomena suggesting disordered action of the heart during convalescence, and that less than 3 per cent., even after assigning the invalidism from unknown causes to D.A.H., were found to be invalided for D.A.H. a year later.

Wilson and Mackintosh in their analysis of 1,500 moderately severe cases in 1918 at the Boulogne base, found that only 125 failed to respond normally to an effort test. After graduated exercise only 19 still failed to pass a test, and, of these, 9 dated their symptoms from a previous illness, one had had the symptoms before the war, 4 were labelled neurasthenic, and only in 5 was gassing the apparent direct cause, that is, about 0·6 per cent. if the neurasthenia be regarded as directly the result of gas.

Meakins and Priestley, in Report No. 16 of the Chemical Warfare Medical Committee, give figures relating to this question in their analysis of the records of 4,575 cases of gas poisoning treated at various hospitals in the United Kingdom, but not under the control of these observers, during the spring and summer of 1918. These cases were chiefly, but not entirely, due to mustard gas. Of the total 17·2 per cent. were detained in hospital for nine weeks or longer, but only one-seventh of these, or 2·5 per cent. of the total, were stated to be suffering from disordered action of the heart.

It is fairly clear from these various statistics that, under competent medical treatment the incidence of D.A.H. in mustard gas casualties should be very low when serious complications, such as broncho-pneumonia, are absent, and that such an after-result is not to be feared with mustard gas to anything like the same extent as it is with phosgene poisoning.

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CHAPTER XIV.

LACHRYMATORS, PARALYSANTS AND SENSORY IRRITANTS.

Lachrymators.

EXPOSURE to a concentration of one part of the vapour of such lachrymators as xylyl bromide or ethyl iodoacetate in two to five million, causes profuse watering of the eyes in a moment or two, and with rather greater concentrations the smarting and pain in the eyes may become intolerable, so that it is impossible to keep them open. The consequent interference with vision is quite sufficient to put a man temporarily out of action. As the concentration of the vapour increases further effects show themselves. The irritant action on the respiratory passages and lungs is rendered evident by a burning sensation in the throat and burning pain or discomfort in the chest, and unless the affected men can withdraw from the poisonous atmosphere, nausea, retching and vomiting soon commence, accompanied by pain in the epigastrium. A man affected to this degree may appear dazed and become somewhat torpid, mainly perhaps from the general intense discomfort and the repeated retching and vomiting, though a direct effect of absorbed vapour may also play a part.

Speaking generally, the casualties that resulted from the German lachrymator shell in France never exhibited more severe symptoms than the above, though a few instances occurred when death was caused by the bursting of one of these shell close to a man, and there was uncertainty in the absence of a *post-mortem* examination how far the fumes were a contributory cause of death in addition to actual violence. Many of the troops experienced simple lachrymation, but the actual number of casualties that reached medical units was small, as has already been pointed out, since even the imperfect respirators and helmets used in 1915 and 1916 could keep out a large proportion of the vapour, while the limited number of lachrymator shell used and the high boiling point of the liquid prevented any high concentration being attained in the open air. The striking feature was the rapidity with which the cases recovered when once they had withdrawn from the poisonous atmosphere. The symptoms of those who were more severely affected had usually abated by the time they reached the advanced dressing stations; at the end of twelve hours there was little amiss with them, and even the redness and swelling of the eyelids and injection of the conjunctivæ which had been conspicuous in the early stages had nearly disappeared. No treatment, other than simple lavage of the eyes, was found necessary, and no further toxic effects developed subsequently.

Casualties of a more serious character sometimes occurred in the factories in England,* where men were engaged in manipulating ethyl iodoacetate or in filling shells with this substance, since there was more opportunity of accidentally encountering a high concentration of the vapour or splashes of the actual liquid. Thus cases occurred of more severe conjunctivitis (even hæmorrhagic in character) and blepharitis than were seen in France, and serious conjunctivitis and keratitis followed by corneal opacity were caused in some instances by splashes of liquid in the eye. Prolonged exposure to the fumes often caused blistering of the exposed skin, and contact with the actual liquid produced an eczematous ulceration, while abrasions or scratches of the skin showed a great tendency to become septic. Cough, tracheitis, bronchitis, and sometimes œdema of the lungs or pneumonia resulted from the fumes. Suppression of the urine for some hours and albuminuria were occasionally noticed.

In one instance when death occurred within twenty-four hours after exposure to the fumes as the result of the accidental explosion of a shell, autopsy revealed œdema and congestion of the lungs, and acute inflammation of the whole of the air tubes from the larynx downwards which increased in intensity in the smaller bronchial tubes, the surface of the mucous membrane being covered and the smaller tubes blocked by a viscid purulent secretion. On microscopic examination the œdema was not very marked, but in parts of the lungs, including the whole of the right lower lobe, the alveoli were packed with extravasated red blood-corpuscles. The mucous membrane of the trachea and bronchial tubes was necrotic and had been shed in places, the submucosa was œdematous and contained extravasated blood, while debris of necrotic mucous membrane, leucocytes, and exudate occurred in quantity in the lumen. The tubules of the kidney showed signs of degeneration. Experiments on animals with this and other lachrymators showed pathological changes of the same type.

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* Report No. 8, Chemical Warfare Medical Committee, by Shufflebotham.

A fatal case of poisoning with ethyl iodoacetate occurred in France in a member of a trench mortar crew owing to the premature explosion of a lachrymator bomb. The *post-mortem* examination showed a condition of acute pulmonary œdema, the œdema fluid being stained with blood, whilst there were multiple small hæmorrhages in the lungs. The skin of other members of the gun crew was blistered.

One other instance of death from ethyl iodoacetate poisoning which occurred in France deserves to be recorded. It was the custom to expose troops to a small concentration of the vapour of this substance in a chamber with a view to testing the fit of the face-masks of their box respirators. On one occasion a man obtained possession of a bottle in which the poison was stored for this purpose, and swallowed a little of the contents under the impression that it was liquor. The stomach was washed out almost immediately, the fluid returned having the characteristic "pear-drop" odour and causing lachrymation amongst the bystanders. The poison acted as a violent corrosive. Pain in the throat and stomach was followed by repeated vomiting, the vomit becoming more and more blood-stained and continuing to show marked lachrymatory properties. The patient finally died in a state of collapse twenty-nine and a half hours after swallowing the poison. The following changes were found at autopsy: congestion and multiple hæmorrhages in the œsophagus and stomach, profuse hæmorrhage in the jejunum, congestion of the other abdominal organs, acute congestion of the lower part of the trachea, and hæmorrhagic congestion of the bronchioles and lungs.

Many of the acute lung irritant gases, especially chloropicrin, have considerable lachrymatory power, as already pointed out.

Paralysants.

Hydrocyanic Acid.—Experimental evidence obtained in the early days of gas warfare made it clear that hydrocyanic acid was practically non-cumulative in action, the actual concentration of the gas being of far greater importance than the duration of exposure. The concentration of the gas which appeared necessary to cause a fatal result was high in comparison with chlorine or phosgene. The question of the real toxicity of the gas was, however, obscured for a considerable time by the fact, which was not at first appreciated, that the susceptibility of different species of animals to the action of the poison varied greatly, dogs being particularly susceptible.

A crucial experiment was made on himself by Mr. J. Barcroft with a view to gaining some idea of the susceptibility of man. He and a dog, both unprotected, entered a chamber, the atmosphere in which contained 1 part of hydrocyanic acid in 1,700–2,000 by volume. He gives the following description of the experiment :—

> " In order that the experiment might be as fair as possible, and that my respiration should be relatively as active as that of the dog, I remained standing and took a few steps from time to time while I was in the chamber.
>
> " In about thirty seconds the dog began to get unsteady, and in fifty-five seconds it dropped on the floor and commenced the characteristic distressing respiration which heralds death from cyanide poisoning. One minute thirty-five seconds after the commencement the animal's body was carried out, respiration having ceased and the dog being apparently dead. I then left the chamber. As regards the result upon myself, the only real effect was a momentary giddiness when I turned my head quickly ; this lasted for about a year, and then vanished. For some time it was difficult to concentrate on anything for any length of time. It is hard to say to what extent this was due to the experiment."

This observation shows that a concentration of more than 1 part of the gas in 2,000 would have to be attained before much effect would be produced on troops in the field.

If the concentration of the gas is high the symptoms follow in rapid sequence ; giddiness, confusion, headache, failure of vision, palpitation, and pain in the chest and over the heart culminate in a few seconds in loss of consciousness, the respiration becomes laboured, being slow with long drawn out inspirations, convulsions set in, and death ensues in one or two minutes from failure of the respiration and then of the heart. Still higher concentrations cause immediate unconsciousness, dilatation of the pupils, a few gasping respirations, and death, with or without convulsions.

Death in these cases is attributable mainly to the direct effect of the poison on the nervous system and the heart, though hydrocyanic acid is a general tissue poison and reduces the oxidative processes of the body, even though the blood contains a copious supply of oxygen.* In the 1918 edition of their official medical pamphlet on gas poisoning, the French drew attention to marked contraction of the bronchial tubes by spasm of the muscle in these cases of rapid death, but apart from this there are no obvious pathological changes, though the interference with oxygen consumption in the tissues may cause the organs of the body to have a brighter red colour when examined soon after death than is usually the case.

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* See Bibliography, Evans.

If, however, the concentration of the gas is much below that which causes rapid death, there is little danger and only giddiness may be produced unless the duration of exposure is greatly prolonged. Concentrations of the gas below 1 part in 10,000 produce little or no effect.

Removal of the case from the poisonous atmosphere is followed by rapid recovery provided that the respiration has not stopped, and even if it has the case can sometimes be resuscitated by artificial respiration if the heart is still beating. No serious after-effects develop, and treatment is therefore practically limited to the immediate measures of dragging the case into pure air and applying artificial respiration, if necessary, coupled with stimulation by splashing cold water on the face and chest, and by friction of the limbs.

The 1918 edition of the official German medical pamphlet on gas poisoning states : " As a rule, only giddiness, and in some cases loss of consciousness of variable duration, occur in addition to irritation of the throat. Low concentrations, such as can occur in the open air, frequently give rise to only slight symptoms, or even to none at all. . . . Recovery takes place, as a rule, in a short time. If a case survives for an hour after the poisoning he is usually unlikely to die." It seems, therefore, probable that the hydrocyanic acid shell used by the Allies were of more value as harassing agents than as casualty producers. The Germans never made use of hydrocyanic acid for offensive purposes, and no accidental cases of poisoning with this substance were reported amongst the British troops in France.

Sulphuretted Hydrogen.—Cases of poisoning with this gas have frequently occurred in sewers, as reported by Haldane. A concentration of 1 part of sulphuretted hydrogen in 500 has an extremely rapid action on the central nervous system and the heart, and causes almost instantaneous loss of consciousness and death in a matter of two or three minutes. With 1 part of sulphuretted hydrogen in 1,000 loss of consciousness is also rapid, but an animal may live for some time, and even ultimately recover if it escapes fatal pulmonary trouble. The effects are much less severe with concentrations below 1 part of the gas in 2,000.* The smell of the gas is unrecognizable in these relatively strong concentrations, but catching of the breath and smarting of the eyes are caused at once, and exposure for any length of time leads to partial stupefaction, and headache and nausea, which persist after reaching fresh air. If exposure is at all prolonged, concentrations of the gas of, or in excess of, 1 part in 10,000 cause the delayed onset of acute conjunctivitis, as well as bronchitis, and in the more severe cases bronchopneumonia and pulmonary œdema. In fatal cases death, if it is not sudden, is due to the effects of the gas on the respiratory system.

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* See Bibliography, Foster and others ; and Lehmann.

On one occasion when the British made a cloud attack with sulphuretted hydrogen five or six cylinders were broken by a German shell. A heavy cloud of gas at once enveloped those who were operating the cylinders. Eight of these men were killed by the gas, and nine others, though gassed, survived. Those who were killed appear to have died rapidly, the corpses in some cases showing deep cyanosis, in others none. In one instance artificial respiration was kept up for two hours without avail. One man was found unconscious in the trench, and when he came round he stated that he felt paralysed all over and could not move his limbs. Several of the other survivors temporarily lost their mental control and had to be forcibly restrained. There is no record in this instance of any subsequent bronchitis or conjunctivitis, though the latter was a marked feature when men were affected by sulphuretted hydrogen in England owing to the accidental bursting of a pipe connected with cylinders of the gas.

Sensory Irritants: the Arsenical Warfare Gases.

All the arsenical poisons used in the war may be regarded as substitution products of arseniuretted hydrogen (arsine), the hydrogen being replaced by chlorine, bromine, cyanide, and phenyl or ethyl radicles. This change to a large extent masked the ordinary poisonous properties of arsenic, the compounds showing chiefly an intense power of irritating certain sensory nerves. Arsenic compounds are known in civil toxicology to possess two main actions: (i) arseniuretted hydrogen, AsH_3, is a gas which, when breathed in air, is absorbed into the circulation, where it causes destruction of the red blood-corpuscles, the development of anæmia and jaundice, and destructive changes in the kidney and liver cells: (ii) arsenious oxide, As_2O_3, when introduced into the alimentary canal, causes a severe and even rapidly fatal inflammatory reaction, with pain in the throat, stomach and abdomen, and with vomiting and diarrhœa. If the poisoning is more protracted, a slowly progressive peripheral neuritis may develop, with persistent loss of the deep reflexes and with sensory and motor defects. The use of toxic arsenical compounds in gas warfare might theoretically have been expected to cause local irritation of the alimentary canal, destruction of red corpuscles, and peripheral neuritis, but actually a very different and novel train of symptoms was produced. Hæmolysis and jaundice were never seen. The local irritation of the alimentary canal was produced almost entirely when men had drunk water from shell-holes contaminated by the poisons. The main features of the Blue Cross poisoning were an immediate and intense local irritation of the naso-pharynx and occasionally a transient paralysis of parts of the nervous system of such a character that by many medical officers it was regarded as being of a functional or hysterical nature.

Diphenyl-chlorarsine, $(C_6H_5)_2AsCl$, and diphenyl-cyanarsine $(C_6H_5)_2AsCN$, are crystalline solids at ordinary temperatures; the former melts at 43° C. and boils at 333° C., the latter melts at 31° C. and has a boiling point above 300° C. N, ethyl carbazol, $(C_6H_4)_2N.C_2H_5$, which was sometimes found in German Blue Cross shell, is also a solid at ordinary temperatures, with a melting point of 68° C. and a boiling point above 190° C., but it has irritant properties of a far lower order than the arsenical compounds. Ethyl-dichlorarsine, $C_2H_5.AsCl_2$, and ethyl-dibromarsine, $C_2H_5.AsBr_2$, are colourless mobile liquids at ordinary temperatures, the former boiling at 156° C. These four arsenical compounds have a faint aromatic odour, and can be dissolved without decomposition in various organic solvents, such as alcohol, ether, or benzol. In the presence of water diphenyl-chlorarsine is decomposed into diphenyl-arsenious oxide, $[(C_6H_5)_2.As]_2O$, and ethyl-dichlorarsine into ethyl arsenious oxide, $C_2H_5.AsO$, bodies of nauseating garlic-like odour which show irritant properties similar to, but much weaker than, the chlorarsine compounds. Diphenyl-cyanarsine is far more stable in the presence of water.

Ethyl-dichlorarsine and ethyl-dibromarsine can exist in the air in the form of a true vapour, but owing to the high boiling point of the liquids only a low concentration of the vapour can be obtained in the air at ordinary temperatures. Diphenyl-chlorarsine and diphenyl-cyanarsine cannot exist as vapour to an appreciable extent at ordinary temperatures, but they are readily dispersed without decomposition by the aid of heat in the form of an intensely irritant smoke, as may readily be seen by heating a trace of the substances on a spatula. A visible smoke consists not of matter in the molecular form of a gas, but of actual particles of extremely minute size, some particles being liquid, as in the case of tobacco smoke, others being solid, as in the case of diphenyl-chlorarsine and diphenyl-cyanarsine. A substance in very fine particulate form can remain suspended in the air for an immense time, and the toxic action of Blue Cross shell depended on the liberation of part at least of the poison as a particulate cloud by the heat and violence of the explosion.

The irritant properties of diphenyl-chlorarsine were recognized by La Coste and Michaelis in 1880, while La Coste in 1881 stated with regard to ethyl-dichlorarsine: " It has a very powerful irritant action on the mucous membrane of the eyes and nose, causes painful blistering of the skin, and is very dangerous for those working with it, since its vapour causes respiratory embarrassment, faintness, and long-lasting paralysis and anæsthesia of the extremities." When Blue Cross shell were introduced by the Germans the nature of their fillings was soon identified by chemical analysis of the contents of blind shells, and more accurate information regarding the toxicology of these substances was then sought by means of experiments on animals and man. The casualties resulting from Blue Cross and Green Cross 3 shell were at first of a puzzling nature, and it would have been difficult to assess their clinical features rightly without a knowledge of the results that had been ascertained experimentally. These experimental observations are therefore given below in some detail, in order to afford a fuller conception of what might have been the result of a more successful use of the arsenic compounds in warfare.

In order to attain for experimental purposes definite concentrations of the poisons in the air a known weight of the substance in question was either dispersed by heat or dissolved in a volatile organic solvent and distributed as a fine spray in the air of a gas-tight chamber. Low concentrations were tested for their immediate irritant properties on man, while the lethal action of higher concentrations was investigated on animals.

The *post-mortem* changes in animals after fatal doses of diphenyl-chlorarsine were mainly confined to the respiratory tract, and were in themselves quite sufficient to account for death.* There was a formation of fibrino-purulent membrane extending from the larynx to the smaller bronchi, which was easily detachable and left a rough surface denuded of epithelium. In cases where the poison had penetrated to the ultimate recesses of the lungs pulmonary œdema was common and frequently severe. There was considerable congestion of the alveolar area, with scattered hæmorrhages, both pulmonary and sub-pleural, where the œdema was considerable and the smaller bronchi blocked. Emphysema was present in the parts of the lung not affected. The action on the alveolar area was, however, far less noticeable than in the case of the acute lung irritant gases, injury to the trachea and bronchial tubes being relatively more prominent. Congestion of the abdominal viscera was present and sometimes well marked. Lesions were sometimes found in the kidney and liver, being mainly confined to congestive and hæmorrhagic changes with epithelial degeneration.

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* See Dunn, Report No. 9, Chemical Warfare Medical Committee.

To obtain effects of this severity it was, however, necessary to employ concentrations of the poison which in the light of what follows must be regarded as considerable. As a rapid lethal agent diphenyl-chlorarsine has roughly speaking about the same toxicity as phosgene, *i.e.*, about the same concentration is required in both cases to cause a fatal degree of injury to the lungs, but ethyl-dichlorarsine is not nearly so powerful in this respect, and some species of animals may survive an exposure for half an hour to a concentration of 1 part of ethyl-dichlorarsine in 10,000 of air without giving evidence of serious pulmonary trouble. That the poison is actually absorbed into the body in these circumstances is shown by the fact that in one of the British experiments a rabbit, which had been exposed to this concentration for half an hour, excreted 0·4 mgm. of arsenic in the urine passed during the twenty-four hours following the exposure, while only 0·01 mgm. had been found in the urine passed during the twenty-four hours preceding the experiment, and in another rabbit $\frac{1}{15}$ mgm. of arsenic was recovered from the lungs after the experiment, no trace of arsenic being found in the lungs of a normal rabbit used as a control. Notwithstanding this absorption of arsenic, British observers were unable to obtain evidence of any alteration in sensory or motor power in rabbits and monkeys exposed for half an hour to concentrations of ethyl-dichlorarsine as high as 1 part in 10,000 of air, even though some of the animals were kept under observation for as long as three weeks after exposure. Apparently lasting symptoms of general disturbance or peripheral neuritis are only caused by absorption of considerable amounts of these organic arsenical compounds of high molecular weight such as may ensue from chronic exposure to low concentrations.

The property, however, which above all others distinguishes these arsenical compounds and renders them valuable for military purposes is their power of causing violent sensory irritation in man, even when they are present in amazingly low concentration, far beneath that required to produce visible lesions of the respiratory tract. The symptoms are quite characteristic ; briefly, they consist of intense pain in the nose and accessory sinuses, in the throat and in the chest, inflammation of the eyes, nausea, vomiting, and great mental depression and misery. The conspicuous pain in the nose which is, especially in mild cases, often accompanied by repeated sneezing, has suggested the names of nasal irritants or sternutators for these arsenical compounds. In man, slight and transitory nasal irritation is appreciable after an exposure of five minutes to as little as 1 part of diphenyl-chlorarsine in 200 million of air, and as the concentration is increased the irritation shows itself sooner and in rapidly increasing severity. Marked symptoms are produced by exposure to 1 part of diphenyl-chlorarsine in 50 million of air, and it may be stated in general that this concentration forms the limit of tolerance of ordinary individuals for an exposure lasting five minutes. A concentration of 1 part in 10 million will probably incapacitate a man within a minute from the pain and distress, and nausea and vomiting accompany an exposure of from two to three minutes to this concentration. The Germans state that diphenyl-cyanarsine is an even more powerful irritant than diphenyl-chlorarsine.

Ethyl-dichlorarsine has, on the other hand, a far lower irritant power. An exposure to 1 part of this substance in 1 million of air for five minutes causes definite nasal irritation and sneezing, but even with this concentration some persons appear to be immune. Exposure for three minutes to a concentration of 1 part in 500,000 of air was found to cause considerable irritation of the nose and throat and a burning sensation in the chest.

A further characteristic of the sensory irritation caused by these compounds is that the symptoms do not commence to diminish as soon as the person affected leaves the poisonous atmosphere, but actually increase in severity for a time before they begin to subside. It may take from half an hour to an hour or two, depending on the severity of the initial symptoms, for the pain to disappear after pure air is reached.

These arsenical compounds exert a vesicant action if applied in strong concentration or in the pure state to the skin, but they are far weaker in this respect than mustard gas. Air saturated with vapour of ethyl-dichlorarsine at ordinary temperatures will produce only the mildest signs of inflammation of the skin even after prolonged exposure, and no instance of vesication could ever be ascribed definitely to the action of the arsenical compounds amongst casualties occurring in France. Flury published in 1921 an extensive account of German experimental data on the physiological action of a great number of arsenical compounds, and in respect to the action of the compounds that actually figured in the war his observations agree fully with the British experience. He regards both the sensory irritant and the toxic properties of these substances as manifestations of true arsenical tissue poisoning.

Morbid Anatomy and Pathological Changes.—As no known fatal cases of poisoning with the arsenical warfare gases occurred in the British armies in France there are no data available as to the anatomical changes occurring in man. It has been pointed out above that if animals are exposed to a serious concentration of these compounds in the air the elimination of absorbed arsenic can be identified in the urine, but the analysis of urine obtained from human casualties resulting in France from Blue Cross or Green Cross 3 shelling gave but dubious evidence of the actual absorption of arsenic. Thus, four men who were believed to have been gassed by Green Cross 3 shell on 2nd July 1918, showed respectively 0·1, 0·1, 0·3, and 0·1 mgm. of arsenic per litre of urine obtained on 27th July; and another four cases gassed probably by Blue Cross shell on 4th August 1918, showed respectively 0·25, 0·1, 0·1 mgm., and a trace of arsenic per litre of urine obtained on 5th August. A little later on, four specimens of urine collected from men who had been in the forward area without being exposed to gas shelling yielded respectively a trace, 0·04, 0·04, and 0·02 mgm. of arsenic per litre. Though at first sight these facts may appear to support the idea that arsenic had been absorbed in significant amount by the men who had been gassed, scepticism in the validity of this deduction is aroused by the close similarity in the values obtained in one instance twenty-four hours and in the other three weeks after exposure to the gas. This doubt is further strengthened by the fact that the A.D.M.S. (Sanitation) records that in 1916, at a time, it is true, when traces of arsenic were found in beer in some of the northern areas and in some samples of *vin ordinaire*, amounts of arsenic varying from 0·02 to 0·24 mgm. per litre of urine were found in several specimens taken from men who were not drawing military rations but consuming food similar to that of French civilians, and from 0·03 to 0·10 mgm. per litre of urine in specimens taken from men consuming military rations.

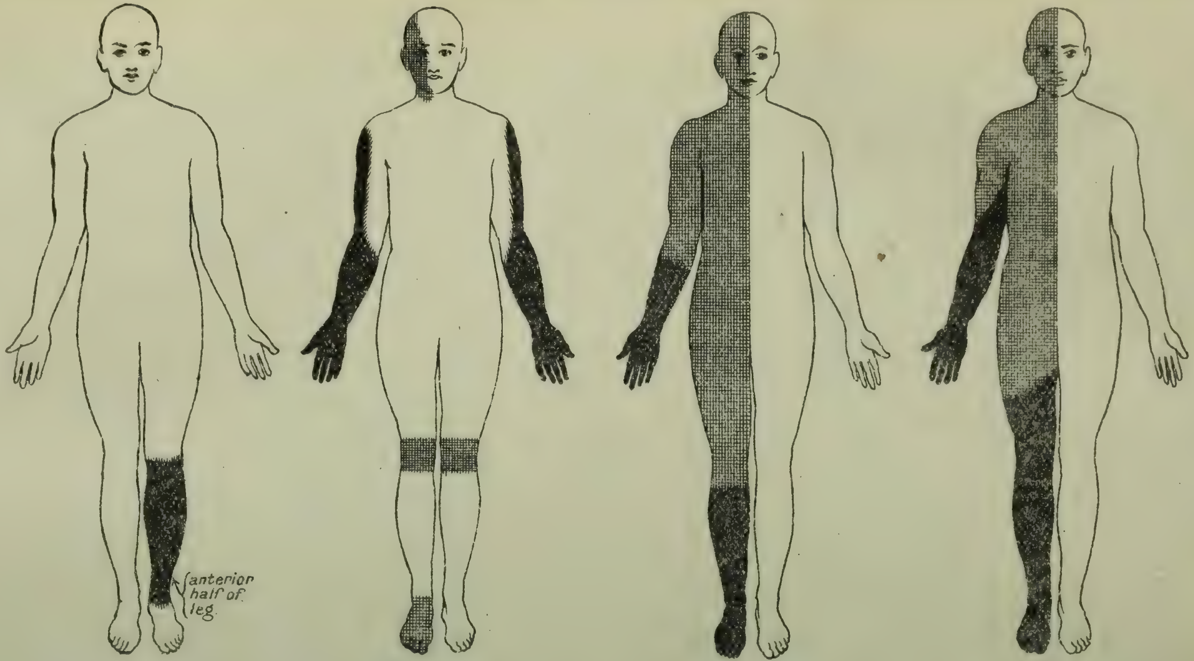
Symptoms, Signs and Sequelæ.—When a man was seriously affected by the fumes arising from a Blue Cross or Green Cross 3 shell the effects began to show themselves within a few moments of exposure and developed in rapid sequence: intense pain of an aching or burning character in the nose, mouth and throat, pain in the gums and jaws, tingling and smarting of the face, especially the cheeks and lips, aching pain in the eyes and frontal headache, watering of the eyes and painful conjunctivitis, copious watery discharge from the nose, tightness and burning sensation in the chest, salivation, pain in the stomach, nausea, retching and sometimes vomiting which might be followed by tenesmus, though diarrhœa was practically never met with. The pain in the nose and throat was not infrequently described as passing upwards into the eyes and head, a fact suggestive of the involvement of the frontal and accessory nasal sinuses. It is by no means easy to describe this pain. If slight it resembled in some degree the pain which is sometimes experienced when fresh water gets into the nasal sinuses whilst bathing, but in the more severe cases it was of distressing intensity and sometimes agonizing. The pain in the chest was always described as of a burning character in the early stages. The degree to which the different symptoms developed differed even in the severe cases. Thus in some cases little complaint was made of distressing pain in the nose or head, and the throat felt unpleasantly dry rather than painful, though an intense burning sensation was felt in the chest. Possibly these differences were dependent on differences in the mode of breathing, for the serious involvement of the nasal passages would be less likely to occur in the case of mouth-breathers. The pain in the eyes was somewhat different from the smarting caused by the simple lachrymators, the impression being gained that small gritty particles had been driven into the eyes. At an early stage when the distress was at its height the skin of the cheeks, especially close to the eyes and nose, might feel tense to the patient and have a slightly swollen look. Sneezing appeared to characterize the mild rather than the severe cases.

A very early condition sometimes complained of was that of giddiness, and a certain number of cases quickly lost consciousness, a comatose condition persisting for several hours. Others in whom consciousness was never lost passed into a lethargic condition for a period of twelve to twenty-four hours. A remarkable feature in these severe cases was the intense mental distress which accompanied the symptoms already described. Even the slighter cases felt and looked miserable and wretched until the irritation had passed off, and the picture of utter dejection and hopeless misery furnished by the severe cases had no counterpart in any other type of gas poisoning. Occasionally the psychical depression resulted in the temporary loss of mental control, and men were in a few instances reported as having acted as if they were driven mad by their pain and misery. In at least one instance a man in this condition had to be forcibly restrained from shooting himself, and in another case a man tried to get under the floor of a hut under the delusion that he was being pursued.

In addition to these changes in the mental condition alterations in motor power were not infrequent. They might supervene within an hour or be more delayed in appearance. Though the commonest complaint was of formication mainly referred to the finger-tips—and this has also been observed in laboratory workers who would not be likely to exhibit functional phenomena—yet temporary paralysis involving one or more limbs was seen in a fair number of cases. In one instance complete paralysis of the left arm developed within three-quarters of an hour after exposure, so that by the time the man reached the advanced dressing station his arm was hanging flail and useless. By the time, however, that he had arrived at the casualty clearing station, an interval of about four hours, this paralysis had almost entirely disappeared, and within twenty-four hours there was no sign left of it. Such instances as these were proportionally infrequent, though they were a strong argument in favour of a central toxic action of the gas which affected the cortical or spinal centres leading to a temporary abolition of function. Again, other instances occurred in which a more generalized motor weakness appeared, and one well-authenticated example of the combination of this motor weakness with mental depression may be quoted. A party of men had been affected by Blue Cross gas and in addition to the irritative phenomena already described they developed a considerable weakness of the legs so that progression was difficult and uncertain. After taking a few steps the men would fall down.

They would very shortly rise and struggle forward again. There seemed very little reasoning power in their progression, and they presented a picture of a loss of mental control which would not permit them to lie still when they fell but forced them to struggle on despite the motor weakness from which they were suffering. The experience of the Germans seems to have been similar, as is shown by the following quotation from Flury : " In addition to the phenomena of sensory irritation, inhalation of diphenyl-chlorarsine may lead to serious disturbances of the nervous system from absorption of the poison. These show themselves as motor disturbances, uncertain gait, swaying when standing, and sometimes complete inability to walk. As a rule they are accompanied by severe pain in the joints and limbs. Inhalation of very high concentrations is also often followed by giddiness, attacks of faintness, and loss of consciousness, which may last for many hours. When considerable quantities of diphenyl-chlorarsine or related organic arsenical compounds are taken through the skin nervous disturbances of various types may arise, and these are to be ascribed not to a local action of the poison but to its general absorption. Hyperæsthesia, anæsthesia and paræsthesia of definite areas of the skin, especially of the lower extremities, could frequently be observed. Twitching of the muscles and convulsions may occur in very severe cases of poisoning by similar substances."

These motor changes in the early stages must be clearly differentiated from the sensory changes occurring later in the course of the illness. The former may with some degree of certainty be ascribed to toxæmia, transitory but definite, of the central nervous system. It is far more difficult to come to a certain conclusion about the latter. The sensory changes were mainly a disturbance of epicritic sensation leading to anæsthesia more or less complete, a condition which commonly supervened about the fourth day. The extent of the anæsthesia varied from a mere numbness of the finger-tips to a complete loss of sensation over a considerable part of one or more limbs. Commonly, however, the affection was bilateral and conformed to the glove or stocking distribution. Reflexes were in these cases unaffected and the sensory condition was not accompanied by any motor change or any sign of trophic disturbance. Pressure on the nerve tracts was not painful, nor was any corroborative evidence of peripheral neuritis obtainable. Naturally, the first suggestion in considering these cases was that an arsenical peripheral neuritis was present, but prolonged and careful observations



(a) CASE 1. (b) CASE 2. (c) CASE 3. (d) CASE 4.

FIG. 1.

DISTRIBUTION OF SKIN ANAESTHESIA FOUND IN FOUR CASES OF PROBABLE CHLORARSINE GAS POISONING.

Areas of marked anaesthesia are heavily shaded, areas of less marked anaesthesia are indicated by cross hatching.

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tended to disprove this view. Progress in all these cases was undoubtedly towards recovery, and in no instance did any indication of involvement of motor nerves develop. Numerically, cases showing this manifestation were very uncommon, and hence the opportunity to decide finally was not forthcoming. The conclusion arrived at, however, was that in all probability these sensory changes were functional in character. An arsenical poisoning should not have the selective power to attack only the sensory cells of the cord, leaving the motor cells intact. Further, the distribution of the anæsthesia was never of a segmental character but was almost always of that glove or stocking distribution which is so significant of functional disorders. Also, recovery was so rapid and so uniform that this formed part of the argument against an organic basis for the lesion.

In illustration of this the following four cases reported on by Captain C. D. Christie, M.R.C., U.S.A., at one of the hospitals at the Rouen base may be quoted. Exposure to the gas shelling was followed within ten minutes by the typical symptoms of conjunctival and nasal irritation, constriction of the chest, nausea, dizziness, and partial disorientation. On the following day the casualties had recovered except for a certain weakness. Three days later at the base they exhibited the following phenomena :—

Case 1. (Fig. 1, *a*.)—Special senses normal. No ataxia. Reflexes normal. Weakness of flexors and extensors of arms and legs. Anæsthetic to all types of sensation, including heat, cold, vibration, touch, and pain over the anterior surface of the left leg.

Case 2. (Fig. 1, *b*.)—Reflexes normal. Muscular weakness of arms and legs. Diminution of all types of sensation on the outer surfaces of arms and forearms, and slightly over the right side of the face. Lumbar puncture showed fluid under increased pressure.

Case 3. (Fig. 1, *c*.)—Special senses and reflexes normal. Loss of power in right limbs. General anæsthesia of the whole of the right side of the body. No nerve tenderness.

Case 4. (Fig. 1, *d*.)—Special senses and reflexes normal. Diminution of muscular power of right limbs. Hemi-anæsthesia of entire right side of body. Acrotaxia of right big toe. Cerebro-spinal fluid under pressure but normal in composition.

In all cases improvement was rapid and recovery complete.

Whilst a final conclusion as to the true nature of these nervous phenomena is difficult to arrive at, since the dividing line between functional and organic changes is one which it is impossible to demarcate with firmness and accuracy, it is certainly true that no lasting organic lesion was produced. Perhaps a transitory poisoning of the central nervous system was responsible for the temporary loss of function on the motor or sensory side or the lethargy that was occasionally noticed. It may be taken as axiomatic that exposure to hostile gas of whatever nature is in itself likely to set up a functional condition, more particularly in drafts exposed for the first time to such an experience. The very nature of such an attack, unseen and of unknown quality, experienced after instruction as to the danger of hostile gas, is liable to start a functional change. Lieut.-Colonel Gordon Holmes, Consulting Neurologist in France, made the following remarks in a report in which he reviewed the evidence bearing on the late nervous disorders that might ensue in casualties affected by the arsenical warfare gases: "After a general intoxication which affects cerebral functions, as ethyl-dichlor-arsine generally does, men tend to be abnormally suggestible, and are consequently liable to retain and incorporate in the system of ideas associated with their condition suggestions such as that sensation is lost in certain areas of their bodies, or that their limbs are weak and cannot be moved. This is now recognized to be the most common origin of hysterical or pithiatic symptoms." The late sensory changes seen in France are therefore to be regarded as in all probability of functional origin.

In some instances areas of cutaneous hyperæsthesia could be mapped out over the chest or abdomen. Such a condition was not confined to cases of poisoning by the arsenical compounds, but it was apparently more common in casualties of this type than in those caused by other warfare gases. Captain J. Ramsay found that these areas corresponded fairly accurately with a segmental distribution from a corresponding area of hyperæsthesia down the spine, and suggested that reflex irritable areas developed in the spinal cord from the affection of some viscus, either lung, stomach or intestine, and were reflected in a true segmental distribution over the corresponding skin areas. Cutaneous hyperæsthesia of this type might persist for four or five days after gassing.

In some cases there were more pronounced symptoms in the respiratory tract in the shape of a mild and evanescent bronchitis. No cases of true pulmonary œdema which can be ascribed entirely to the action of shell containing the arsenical compounds were met with, but a certain number of men did present for a period signs of bronchial catarrh as evidenced by a few scattered rhonchi and râles and a certain amount of muco-purulent secretion. A rise of temperature was extremely uncommon, and only rarely were cases seen in whom the temperature exceeded normal. One group of cases, however, showed a marked pyrexia lasting for forty-eight hours. The temperature ran up abruptly to 103° F. and came down by lysis. In only one of these cases was bronchial irritation noticed, and that only to a very slight degree. Whether the rise of temperature was due to the gassing or to some other cause was not determined, but as the cases occurred at a time when the epidemic of mild influenza was raging, it is quite possible that the latter infection was the cause of the pyrexia rather than the gassing.

The solid and even the liquid arsenical compounds were liable to contaminate the ground in and around the crater made by the explosion of the shell containing them, and when rain had fallen and the shell craters were consequently filled with water, the water in its turn became seriously contaminated and was a source of danger to anyone who made use of it. In one instance the clear liquid taken from such a shell-hole was found to contain arsenic in an organic combination equivalent to no less than 20 mgm. of As_2O_3 per litre, and the muddy liquid arsenic equivalent to 80 mgm. of As_2O_3 per litre. The symptoms following poisoning by drinking contaminated water resembled very closely those resulting from inhalation poisoning, but the gastro-intestinal irritation was more pronounced. Nausea, retching and vomiting were more marked, and the intestinal condition of tenesmus was frequently noted. In cases, again, where the contaminated water was employed for washing purposes, the complaint of skin symptoms rather dominated the picture, the men complaining of great burning of the skin with a sensation of tightness and swelling, though these symptoms were subjective rather than objective since no definite œdema was observed beyond a slight puffiness, in part no doubt due to the conjunctival irritation. This is well illustrated by the following instances :—

Six men of the 2nd Battalion Oxford and Bucks Light Infantry infused tea drawn from a sand-bag left by the previous occupants of the trench, using water which they stated was brought with them from their battalion headquarters. One of them did not drink the tea. The other five shortly after drinking it complained of illness, and reported at the aid post. They complained of lachrymation and of weakness and numbness of the arms and legs ; their throats and noses were burning, and they could hardly speak. In addition, they coughed and vomited violently. Samples of the tea mixed with sugar obtained from the sand-bag and of the infused tea-leaves were analysed. The former showed no trace of arsenic, but the sample of infused tea-leaves contained a quantity corresponding to 6 mgm. of As_2O_3 per 100 grm. of the wet leaves. This is equivalent to 14 mgm. of diphenyl arsenious oxide per 100 grm. of the leaves. In this case there can be no doubt that the poisoning was due to the water from which the tea was made having been contaminated with some arsenic compound, probably derived from Blue Cross shell, and the occurrence gives a very definite picture of this method of poisoning.

Another example of water contamination occurred in the 18th Battalion of the London Regiment in January 1918 :—

> Two officers and thirty-one other ranks of No. 2 Coy. obtained water from a shell-hole for washing and shaving. After doing so they complained of great burning in the eyes and gums, which subsequently developed into swelling of the mouth and conjunctivitis. Those who only washed in the water were affected by a splitting headache, intense stinging of the face, swelling up of the cheeks, marked lachrymation, and soreness of the throat. Men who washed their teeth in the water complained of acute burning in the gums. Two or three who drank the water suffered from vomiting. Water obtained from the shell-hole in question was found to be heavily contaminated with arsenic in organic combination, equivalent in amount to 3·75 mgm. of As_2O_3 per litre. No. 1 Coy., who were immediately on the flank of No. 2 Coy., had no casualties, but they drew their water from the water-cart.

Such stable organic arsenical compounds as diphenyl arsenious oxide or ethyl arsenious oxide, which are formed by the hydrolysis of the warfare gases, might therefore contaminate water for long periods, and were capable of setting up a train of toxic symptoms if employed for drinking, cooking, or washing. This necessitated the issue of stringent orders that within the shell area no water from shell-holes was to be employed by the troops for any of the above-mentioned purposes. The identification by analysis of such contamination is not easy, since Marsh's test, Gutzeit's test, precipitation by sulphuretted hydrogen, etc., fail to indicate the presence of these organic arsenical compounds. It is necessary first to destroy the organic matter and to convert the arsenic compound into the form of arsenious acid before proceeding with one of the recognized tests. The following method was found satisfactory at the Central Laboratory, General Headquarters :—

> Evaporate 1 litre of the suspected water to dryness on the water-bath, transfer the solid residue to a long-necked hard glass flask (Kjeldahl flask), add 1 c.c. of concentrated nitric acid (or 2 c.c. if there is much chalk present) and 25 c.c. of concentrated sulphuric acid. Heat over asbestos gauze for at least six hours at a temperature just below the boiling point of the sulphuric acid. Keep the flask inclined to prevent spurting. Allow to cool and dilute to 250 c.c. with distilled water. Pass sulphur dioxide through the solution for twenty minutes to reduce the arsenic acid to arsenious acid. Boil off the sulphur dioxide and test the solution by Marsh's method.

One other possible source of poisoning must be noted as a few cases apparently occurred in this way. Wood from a house which had been destroyed by bombardment was used by a small party of men in making a fire in a cellar. These men all shortly developed symptoms of poisoning by arsenical warfare gas. It was not at all likely that the cause was to be found in food contamination since the water came from a known and uncontaminated source, and the probability is that the wood had been splashed with the contents of Blue Cross shell during the bombardment, and that the heat volatilized the poison and caused the train of symptoms.

In summarizing symptoms, the important feature to emphasize is the immediate action of the poison. The simple lachrymators, too, have an immediate action, but the disability caused by the arsenical compounds is of a much more severe and general type than that due to such substances as xylyl bromide. The vapour of the simple lachrymators is in addition far more easily stopped by a respirator than is the particulate cloud of the solid arsenical warfare gases. In respect to their immediate action, the arsenical compounds differ fundamentally from those warfare gases whose main action is delayed in appearance, for mustard gas does not usually produce any effect for two or three hours, whilst even the acute lung irritants, unless in very high concentration, may produce little effect beyond coughing and nausea for several hours. Inhalation of the arsenical warfare gases is followed by dramatically rapid effects—nausea, pain, conjunctivitis, sneezing, etc.—and the full action of the poison is reached within a surprisingly short space of time, whilst disablement results from the inhalation of concentrations of the poison so small that in the case of any other warfare gas they would be totally ineffective. These features serve to place the arsenical warfare gases in a separate category for tactical employment, and they may be regarded as agents specially adapted for inducing immediate disability, a comparatively brief and harmless action as judged from the purely medical aspect, but one which may have far-reaching effects at the moment of combat from a tactical point of view.

Progress of the Cases.—The preceding description of the symptoms may be taken as applying to the most severe type of casualties met with in the field, but such cases were in the minority, and in many instances the irritant effects were so slight and transitory that the affected men never left their units. The progress of patients affected by the arsenical warfare gases, from whatever source, was in the main uniformly good and rapid to convalescence. The symptoms abated within twenty-four hours, and by forty-eight hours the great majority of the cases had practically recovered. The last symptoms to disappear were gastric discomfort and pain in the nose and forehead, and when these had cleared up, beyond a general weakness with no physical signs and a certain amount of mental depression or mental irritability, the whole condition disappeared in the course of a week. So rapid was the progress on the whole that it was part of the army routine to retain the cases in the forward area rather than evacuate them to the base. Even of those evacuated to the base, either from pressure on beds at the casualty clearing stations or because of the severity of their symptoms, a large proportion were convalescent on arrival. At No. 7 Stationary Hospital, Boulogne, of 239 admissions 190 were convalescent when admitted. Of cases retained in the army area the great majority were fit for duty within ten days.

Of those evacuated to the base, only in rare instances was transfer to a home hospital necessary, and that often for reasons additional to gassing. The symptoms that led to prolonged invalidism were but slight and could hardly be ascribed definitely to the action of an absorbed poison. As a rule they consisted of mild pharyngitis, slight bronchitis, or abdominal discomfort, and indefinite debility, the last being on the whole the most constant feature. The after-effects were no more severe in the case of those who had used water from shell-holes contaminated with the contents of Blue Cross shell; presumably the violent vomiting which quickly ensued when such water was drunk removed most of the poison from the stomach. The debility, which in itself had no characteristic features, may possibly have owed its origin to the poison—a mild form, so to speak, of that acute mental depression which was apparent in the early stage in the severe cases. It must be remembered, however, that throughout the greater part of 1918, when the Blue Cross shelling reached its maximum, the troops were under continual stress owing to the severity of the fighting, and that when once they reached hospital, worn out by the strain under which they had been labouring, it may have been difficult to bring them up to a condition of fitness again, even though the immediate cause of the invalidism may have been trifling in itself.

To give some idea as to the duration of invalidism in ordinary casualties resulting from the arsenical warfare gases the following particulars may be quoted regarding a batch of casualties resulting from Blue Cross shelling in the Bapaume–Achiet-le-Grand area on 25th August, 1918. The shell in question consisted practically entirely of the Blue Cross variety ; there is no evidence that Green Cross 3 shell were used. Blue Cross shell obtained from the captured German ammunition dumps in this region were found to contain in some cases diphenyl-chlorarsine, in others diphenyl-cyanarsine. The usual acute symptoms developed during the bombardment, but twenty-four hours later all that the casualties complained of was a certain amount of headache, dryness of the throat, abdominal discomfort, and in some instances a little dry cough. No abnormal physical signs could be detected. Ten of these casualties were traced to the Rouen base. Of these, seven were transferred to the convalescent depôt at Trouville on the fifth day after gassing, one to the convalescent depôt, Rouen, on the eighth day, while two were evacuated to England, one complaining of dry throat and chest, the other suffering from burns on the scalp, possibly due to mustard gas. Twenty-seven casualties from the same batch reached the Boulogne base. Of these, 21, or 77·8 per cent., returned to duty with their units, 2, or 7·4 per cent., to duty at the base, and 4, or 14·8 per cent., were evacuated to the United Kingdom. The time elapsing between gassing and disposal to duty of the 21 cases who returned to their units was as follows :—

1st week	*Nil.*
2nd ,,	3 = 14·3 per cent.
3rd ,,	7 = 33·3 ,,
4th ,,	3 = 14·3 ,,
5th ,,	4 = 19·0 ,,
6th ,,	3 = 14·3 ,,
7th ,,	*Nil.*
8th ,,	*Nil.*
9th ,,	1 = 4·8 ,,

This last patient had suffered from chronic myalgia of the legs. Of the two cases discharged to duty at the base, one was discharged on the seventeenth day, the other on the twenty-second day, the latter being affected by a deformed leg but exhibiting no effects from gassing. Of the four cases transferred to the United Kingdom, two were evacuated for conditions other than gas poisoning, the third suffered from dyspnœa and fast pulse, the fourth from debility. Those who were disposed of to duty with their units only exhibited the slight symptoms to which allusion has already been made ; no one of these casualties showed at any time even the slightest alteration in sensory power.

Prognosis.—From the description given it will readily be appreciated that the prognosis was uniformly good in the case of the casualties seen in France, no matter how severely they were affected in the early stages. All the facts pointed to the conclusion that the casualties could only have been caused by extremely low doses of the poison, a fact that was substantiated by the accurate experimental determination of the minuteness of the concentration required to produce violent irritation and distress. There can be no doubt that Blue Cross shell were a very inadequate means of disseminating effectively the arsenical compounds of high boiling point ; had higher concentrations been attained in the field the after-effects might have been much more serious. Yet the main importance of this class of compound from the military point of view rests in the extreme sensory irritation and mental distress provoked by mere traces of the substance in the air, effects which can only be avoided by the use of an efficient respirator. On the other hand, long-continued exposure to minute doses in the factories has been seen to cause remote effects. Circulatory disturbances, digestive difficulties, with loss of appetite and weight, and lack of sexual desire in young married men were noted. The most disabling condition met with was a chronic inflammation of the exposed skin areas, associated with œdema and lymphangitis, eczematous ulceration of the hands, and indurated sores between the fingers and on the dorsal aspects of the hands. Irritability of temper, headaches, and insomnia were amongst the nervous effects seen.

Diagnosis.—In the early stages a diagnosis could be arrived at in clear-cut cases from a consideration of the symptoms already described. The following points were of assistance :—

(*a*) Association very commonly with what appeared to be only high explosive shelling.

(*b*) Immediate onset of symptoms, especially conjunctival and nasal irritation, nasal and pharyngeal pain, sneezing, and nausea.

(*c*) Cerebral affections whether tending to lethargy and depression, loss of consciousness, or irritability were characteristic.

(*d*) The rapid progress to recovery was a valuable diagnostic sign where others were absent.

In the later stages diagnosis might be dependent largely on the history. The appearance of sensory changes was of value in arriving at an opinion.

It frequently happened that cases of mixed poisoning were met with. Vesication was so unlikely to be caused in the field by the arsenical compounds that its occurrence offered strong presumptive evidence of the presence of mustard gas as well. So also pulmonary œdema would suggest that an acute lung irritant had played a part in addition to an arsenical compound. Liaison between the medical units concerned and the divisional gas officer or corps chemical adviser was extremely helpful in these circumstances, as the officers of the gas services often had reliable information as to the character of the gas shelling and could therefore render the medical officer more confident in the correctness of his diagnosis.

Treatment.—In the early stages pain is the one symptom calling for relief, beyond the application of the general principles of treatment of all gas cases—rest, fresh air, removal of contaminated clothing and equipment, and light diet, preferably a fluid one. The pain may be intense and is best relieved by inhalations of chloroform, which may conveniently be put up in glass capsules holding 1 or 2 c.c., or by sniffing up a 2 per cent. solution of sodium bicarbonate into the nose and douching the eyes and gargling the throat with the same solution. Another remedy which afforded some relief was the inhalation of ammonia, ampoules originally issued for use in chlorine poisoning being employed. For the pharyngeal irritation and pain glycerine and menthol jujubes were found useful. In very rare instances anæsthetics or morphia hypodermically were necessary to relieve the agonizing pain.

In the later stages treatment should be directed to toning up the physical and nervous systems. The muscular weakness requires graduated exercises under discipline combined with an attractive diet. The mental condition is best met by a suitable environment and a happy combination of work and amusement. When sensory phenomena persist a cure will frequently be obtained by suggestion or by faradism.

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CHAPTER XV.

POISONOUS GASES NOT USED FOR OFFENSIVE PURPOSES.

Nitrous Fumes.

NITROUS fumes have an action typical of the acute lung irritant gases. Though the fumes are somewhat less toxic than chlorine, they are particularly dangerous owing to the fact that they do not cause very great sensory irritation, and men frequently fail to recognize the danger of an atmosphere containing nitrous fumes since they may suffer but slight irritation of the eyes and be troubled but little by coughing. Delay in the onset of acute symptoms is usually a marked feature. According to Irvine, on withdrawal from the poisonous atmosphere no very definite subjective or objective symptoms may show themselves for some time, but acute pulmonary œdema may supervene four to eight hours after exposure, and progress with alarming rapidity, death often ensuing in a few hours. Haldane* found that exposure of mice to as little as 5 parts of nitrous fumes in 10,000 of air for half an hour caused death from bronchitis within twenty-four hours.

In cases of this type the hæmoglobin of the blood remains practically normal in character, but exposure to very high concentrations of the gas may cause the formation of some methæmoglobin and nitric oxide hæmoglobin, though even then death is to be attributed to the pulmonary œdema and not to the changes in the blood.

Though nitrous fumes caused no material cases of poisoning in the warfare on land, a number of instances were reported by Fairlie in the navy owing to the liberation of these fumes from burning cordite. The symptoms, both in their development and general character, corresponded closely with the description previously given by Macaulay and Irvine. A long latent period before the onset of acute pulmonary œdema, which varied in fatal cases from an hour or two up to as long as seventeen hours, followed by the rapid development of urgent symptoms, was a prominent feature in these cases. As regards treatment, valuable results were obtained by the use of emetics in the early stages and venesection.

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* See Bibliography, Foster & Haldane.

Carbon Monoxide.

Carbon monoxide poisoning as it occurred during the war, its treatment, and the requisite preventive measures, are fully described in Chapter XX of this volume. It is necessary, however, to refer to it briefly in order to make clear the essential difference between poisoning with carbon monoxide and poisoning with warfare gases.

Carbon monoxide owes its poisonous properties solely to the fact that it combines with hæmoglobin to form a dissociable compound just as does oxygen, though the affinity of carbon monoxide for hæmoglobin is about 240 times that of oxygen. If blood is exposed to an atmosphere containing both carbon monoxide and oxygen, the proportions of carbon monoxide hæmoglobin and of oxyhæmoglobin which are formed are determined by the laws of mass action, the hæmoglobin dividing itself between the two gases according to their relative partial pressures. Thus, if blood is saturated *in vitro* with normal air (20·9 per cent. of oxygen) containing 0·085 per cent. of carbon monoxide the hæmoglobin will finally become equally divided between the two gases, or 50 per cent. saturated with carbon monoxide. If the concentration of carbon monoxide in this air is raised to 0·255 per cent., equilibrium will be reached when the hæmoglobin is 75 per cent. saturated with carbon monoxide; if it is reduced to 0·028 per cent., equilibrium will occur with the hæmoglobin 25 per cent. saturated with carbon monoxide. A similar partition of the hæmoglobin in the blood between the two gases occurs when a man breathes air containing a small proportion of carbon monoxide, and as the saturation of the hæmoglobin in the blood with carbon monoxide increases and the oxygen-carrying power of the hæmoglobin progressively diminishes, symptoms of anoxæmia begin to show themselves. The serious effects of carbon monoxide poisoning are in fact to be attributed to anoxæmia arising from the fact that the blood can no longer adequately fulfil its function of transporting oxygen; there are no changes in the lungs which might hinder the access of oxygen to the blood as there are in the case of the acute lung irritant gases. Yet reduction of the oxygen-carrying power of the blood by saturation of a certain proportion of the hæmoglobin with carbon monoxide has a far more severe effect than reduction of the hæmoglobin to a similar degree by some form of anæmia, for with partial saturation of the hæmoglobin with carbon monoxide the dissociation of any oxygen carried by the hæmoglobin is rendered more difficult, the oxygen being in fact liberated in the tissues at far lower partial pressures than would otherwise be the case.

The great danger of carbon monoxide lies in the fact that it is colourless, odourless, and non-irritant, and the onset of symptoms may be so insidious that a man may never grasp the danger of the atmosphere he is in till his attention is called to it too late by loss of power in his limbs.

With massive doses loss of consciousness is rapid, and there may be convulsions as a prelude to death. When the concentration of carbon monoxide in the air is relatively low, the symptoms develop very gradually since the gas is only absorbed slowly. If a man is at rest in a concentration of 1 part of carbon monoxide in 1,000 it will take two hours before giddiness appears, and he will not be definitely disabled until two and a half hours have elapsed. The rate of absorption of the gas is much accelerated by muscular exercise owing to the increase in the breathing and in the circulation rate, while the symptoms become accentuated since the oxygen requirements of the body are much greater than at rest. With a concentration of carbon monoxide of 2 parts in 1,000 a man will be seriously affected in half an hour if he is performing a moderate amount of muscular work, and this concentration may prove fatal with prolonged exposure. The rapidity with which small animals, such as mice and small birds, develop symptoms of carbon monoxide depends on their high relative metabolism, which is some fifteen times that of man, and hence they are used to test atmospheres suspected of containing carbon monoxide, since they will be overcome long before man, with his far lower relative metabolism, begins to show any definite signs of poisoning, though, given time, the man will eventually be reduced to the same state as the animal.

With moderate doses, which are, however, sufficient to cause death, the symptoms, which are essentially those of uncomplicated anoxæmia, develop in the following sequence. The first sign is frequently a feeling of loss of power in the limbs. Giddiness, slight confusion of mind, and breathlessness and palpitation on the least exertion also show themselves. The confusion of mind and loss of power in the legs frequently preclude a man from withdrawing from danger, even though he is dimly aware that safety is only a few yards distant. The failure of power in the limbs and the mental confusion rapidly increase, and the man may appear drunk, shouting incoherently, laughing, swearing, or praying. Apathy and complete helplessness supervene, and failure of the intellectual powers gradually passes into complete unconsciousness, which may finally terminate in a painless death. With low doses the extent to which the symptoms will develop is dependent on the degree of the saturation of the hæmoglobin with carbon monoxide which is eventually reached under the mass influence of the carbon monoxide and the oxygen in the air breathed, and on the length of the exposure when once equilibrium is attained. Even in cases of mild gassing with carbon monoxide severe headache accompanied by nausea, similar to that experienced in mountain sickness, is liable to develop.

Recognition that simple anoxæmia is the cause of these symptoms at once suggests the proper lines of treatment. The case must be removed from the poisonous atmosphere as quickly as possible and carried into fresh air. Any increase in the oxygen requirements of the body must be avoided, and the case must therefore be kept at rest. A man moderately gassed with carbon monoxide may fall unconscious if he attempts to walk ; some, in fact, lose consciousness as soon as they reach fresh air, though others may begin to shout and struggle, when it is necessary to control their movements, and it has to be remembered that men in this condition are not responsible for their actions.

The other essential is the proper administration of pure oxygen. As carbon monoxide is a dissociable compound the unfettered mass influence of the oxygen in the air begins to expel carbon monoxide from its combination with hæmoglobin as soon as an atmosphere free from gas is reached. The process is somewhat slow owing to the high affinity of carbon monoxide for hæmoglobin, but in an hour or two the blood will be entirely freed from the gas. This expulsion can be rendered five or six times as fast by the administration of pure oxygen, since the alveolar air in the lungs only contains about 14 per cent. of oxygen when ordinary air is breathed, and half an hour to one hour's efficient and continuous administration of pure oxygen (care being taken that the expired air is not rebreathed) will be sufficient to get rid of all the carbon monoxide from the blood and render the oxygen-carrying power of the blood normal again. If the breathing is shallow or threatens to fail, artificial respiration as well as oxygen administration will be necessary. It will be evident that the object aimed at in this case by oxygen administration is quite different from that in cases of acute pulmonary œdema caused by the acute lung irritant gases, where it is necessary to contend with long-lasting cyanosis and oxygen want. When once the carbon monoxide has been expelled from the blood there is no advantage in continuing oxygen administration, unless cyanosis should set in at a later stage owing to the development of pneumonia or cardiac failure. The usual precautions for combating collapse should also be taken in severe cases of carbon monoxide poisoning.

Death occurs when saturation of the hæmoglobin with carbon monoxide reaches about 80 per cent., but lower degrees of saturation may prove fatal if they are kept up for long, for the longer the duration of the anoxæmia the more difficult is it for the organs of the body to recover from the effects. Consciousness is, as a rule, not immediately regained on the expulsion of carbon monoxide from the blood. If a case remains unconscious for twenty-four hours after removal from the poisonous atmosphere the prospect of recovery is to be regarded as dubious, for the central nervous system and the heart may have been too profoundly affected by the preceding anoxæmia, though cases have been known to recover even after forty-eight hours of unconsciousness. The harmful effect of the period of severe anoxæmia may further be indicated by such sequelæ as paralysis of single muscles or groups of muscles, different forms of mental disturbance, or cardiac dilatation. In view of the last effect caution must be taken that too great a strain is not thrown on the circulation during convalescence after severe carbon monoxide poisoning.

Arseniuretted Hydrogen.

This gas is typically cumulative in action. Exposure of animals for about six minutes to 1 part of arseniuretted hydrogen in 1,000 may cause death in about twenty-four hours. With lower doses the effect is nearly proportional to the product of the concentration of the gas and the duration of the exposure, a concentration of 1 part of the gas in 100,000 being fatal after about twelve hours' exposure.

The gas acts upon the red blood-corpuscles causing intense hæmolysis, and this effect seems to be the main cause of the symptoms. In slight cases there is only jaundice and anæmia, associated with a feeling of malaise, nausea, and pains about the body. In more severe cases there is hæmoglobinuria as well as jaundice and profound secondary anæmia. In bad cases vomiting sets in in an hour or two, with intense pain in the back, weakness, fainting and collapse ; hæmaturia is intense and acute nephritis occurs with casts in the urine. In fatal cases there may be total suppression of the urine. Death seems to be due either to the nephritis or to the want of oxygen caused by the destruction of the red blood-corpuscles and loss of hæmoglobin. The nephritis appears to be largely dependent on the accumulation of hæmoglobin or its derivatives in the kidney. Peripheral neuritis is a not uncommon symptom in the later stages of non-fatal cases.

In the cases of arseniuretted hydrogen poisoning which occurred during the war in certain submarines, the main symptoms, as described by Dudley, were: vomiting—a constant and troublesome symptom often associated with burning and griping abdominal pain—dyspnœa on exertion, anæmia, jaundice, hæmoglobinuria, and albuminuria, headache, and slight œdema of the face and eyelids. Many of the cases gave evidence of a slight degree of neuritis in the shape of tingling and " pins and needles " in the hands and feet. The anæmia was occasionally severe, for some of the cases admitted to hospital showed only two million red corpuscles per cubic millimetre of blood and a hæmoglobin percentage of only half the normal amount. Hæmoglobinuria ceased within three days of leaving the submarine, though slight albuminuria continued in an intermittent fashion for some time longer. The jaundice usually disappeared within a week or ten days. The symptoms of neuritis took two or three weeks to pass off, and a considerably longer time was required before the blood resumed its normal character, though the cases had all recovered completely at the end of six weeks.

Reduction of Oxygen in the Atmosphere.

One instance of asphyxia due to simple reduction of oxygen in the atmosphere may be quoted. The s.s. " Arabic " was wrecked and sunk close to Boulogne, but was subsequently salved and brought into the harbour. Later on a salvage party was set to work to clear out the grain with which the ship had been laden. The work had been carried out for some time without accident, when one day the working party immediately on descending into the hold were overcome without previous warning by dizziness, failure of vision, loss of power in the arms and legs, and loss of consciousness. It was possible to drag some of the men rapidly from the hold, when they quickly recovered, and no further symptoms developed later on, though some had headache for a time; but three men died before they could be rescued. At first it was suggested that carbon monoxide might be responsible for the effects, but there was no source from which it could have arisen and the blood taken from the fatal cases showed no trace of this poison. The symptoms were exactly what would be expected if the men had entered an atmosphere in which the oxygen was greatly reduced. There is little doubt that in this case the sodden and decomposing grain had absorbed a great proportion of the oxygen from the air in the hold. Other gases might have been formed, but if so they can have played but little part. None of the survivors showed any symptoms suggestive of sulphuretted hydrogen poisoning, nor had they experienced on this or on any of the previous days the panting which one would associate with the presence of a material quantity of carbon dioxide. Once or twice previously they had noticed dizziness and weakness of the limbs whilst at work, these symptoms disappearing rapidly if they stopped work for a few minutes, a fact which suggests that on the day of the fatal accident the natural ventilation of the hold was worse than usual.

The remedy in such cases as this is to test the air before anyone enters it, and if necessary either to arrange for proper ventilation, or else to equip the workmen with mine rescue apparatus. No man ought to enter an atmosphere about which there is any suspicion without at least having a life-line attached to him so that he may be pulled out of the dangerous atmosphere at once, should it be necessary. If he has stopped breathing by the time he is got into fresh air artificial respiration should be tried immediately.

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CHAPTER XVI.

THE HANDLING OF GAS CASUALTIES.

THE introduction of gas warfare presented to the medical services an urgent, new, and ever-changing problem which, from both the administrative and the clinical sides, bristled with difficulties. In the early stages the gravity of the resulting casualties was a matter of profound clinical importance, whilst, as the war proceeded, the increasing number of men affected created administrative problems of dealing with gas casualties in mass.

Adequate treatment of gas casualties can only be carried out when medical officers have been trained to recognize the various types of gas poisoning that may occur in war. Whilst the actual number of poisonous organic and inorganic compounds which can be used in the field is limited by many factors—persistence, vaporization, boiling point, etc.—their number is yet so great that the classification, now established, into groups according to the most pronounced clinical results produced is, at any rate for the time, the most useful one to maintain, and on which to base instruction. This presupposes a wide clinical knowledge of the action of gases, both those which have already been identified and employed in the field and also those which, from the general principles governing the employment of gas, may in future be introduced. New clinical features arising from new poisons will then at once be recognized and appropriate treatment can be devised.

In addition to sound clinical knowledge, the medical officer should also be conversant with the tactical aspects of gas warfare, as, for instance, the type of shell employed and the probable object of the enemy in utilizing any particular gas. The combination of clinical and tactical knowledge will alone give a true conception of how to handle casualties, both individually and in the mass. In treatment of the individual casualty clinical knowledge is important, because his chances of recovery may largely depend on the promptitude with which he is treated, and on the time and method of his evacuation. For the mass of casualties tactical knowledge is important to guide administration if undue congestion in medical units is to be avoided and unnecessary evacuation to the lines of communication prevented. A simple illustration will make this clear.

If a heavy bombardment with mustard gas floods the medical units with cases, the urgency of evacuating to lines of communication is by no means so pressing as it would be if a similar number of cases from lethal gas or chlorarsines had occurred. In the former instance an enemy advance over the contaminated area is unlikely, whereas in the latter the bombardment may well be a prelude to such an attempt.*

The efficiency of a medical service may be best gauged not by the efficiency of treatment of the individual, but by the effective handling of cases in the bulk. The flooding of medical units with an enormous number of cases in all grades of severity was a great test of efficiency. As gas casualties progressively increased in number, until they formed some 20 per cent. of the total battle casualties, increasing provision had to be made to classify according to severity and also to provide for the large number of cases in whom objective signs were not present. The establishment in army areas of gas centres for cases not yet diagnosed proved a very great help. These centres were run on the same lines as the centres for " not yet diagnosed " nerve cases, such as shell-shock. Casualties were brought to them for investigation from the clinical side, and for confirmation from their units as to the likelihood of their having been exposed to gas. More particularly were these centres of value in dealing with the light chlorarsine cases, in whom clear objective signs were rarely obtainable and diagnosis had to depend largely on symptoms.

There is no doubt that exposure to a minimal dose of gas was in many cases the final blow which led to a man collapsing in a state of exhaustion after prolonged exposure in the firing line. A true diagnosis in these somewhat difficult cases was made possible at these centres. They were also of great value in the handling of the light cases whose retention in the army area was necessary and who only required a period of rest in a convalescent centre.

Just as, at the base, convalescent depôts prevented wastage to the United Kingdom, so the extension of the same method of treatment to the army areas by means of corps or divisional rest stations was of enormous value. The N.Y.D. Gas Centre soon developed into a convalescent centre for the lightly gassed as well as a unit for accurate diagnosis.

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* Theoretically this is true, but in practice the evacuation of mustard gas casualties may possibly be through casualty clearing stations receiving the mass of the casualties from an attack on a sector immediately to the right or left of the mustard gas attack; so that evacuation to the lines of communication will become as urgent for the mustard gas casualties as for others in such an event, in order to avoid congestion of the casualty clearing stations.—E.-in-C.

The specific actions of the various groups of gases indicated a broad classification of the casualties :—

(*a*) Slight—from the lachrymators and the chlorarsines.
(*b*) Early acute—from the lung irritants.
(*c*) Late acute—from the vesicants.

From a consideration of this classification may be deduced the problems of evacuation and of treatment, which must be considered together. The experience of the war showed the necessity of the administrator and the clinician co-operating in the closest possible manner if time and labour were to be saved.

Where a large number of casualties are occurring simultaneously, it is certain that a percentage of men will be sent to medical units complaining that they have been gassed. This more particularly applies to raw troops exposed for the first time to a possible gas bombardment. The combustion fumes of high explosive may be mistaken for gas fumes. Also the possibility of malingering must always be borne in mind. It may be stated as an axiom that a dose of gas sufficient to cause harmful results will practically from the first reveal some sign to the trained observer. The necessity, therefore, of adequate training of medical personnel in order to check wastage from trifling cases can hardly be exaggerated.

It is interesting to note the experience of the Americans in this respect. Their troops received a very thorough training in the possibilities of chemical warfare, and probably the desire to impress upon them the necessity of gas precaution led to a state of undue nervousness as to gas. During the war the American troops suffered 224,089 battle casualties, and no fewer than 70,552, or 31·5 per cent. of these were caused by warfare gas alone, according to Fries and West. The mortality amongst these gas casualties was less than 2 per cent. The proportion of gas casualties to total battle casualties was considerably higher in the American than in the British armies, while the mortality was distinctly lower, and these facts suggest that the gas casualties among the American troops were on the whole of a distinctly milder type than those which the British experienced.

Where real gas poisoning does exist it is obvious that great caution must be exercised in the evacuation and transport of the lung irritant cases, especially in the early stages. From the first moment such a case must be treated as a " lying " one in order to minimize the danger of pulmonary œdema. This was recognized quite early in the war, and instructions to that effect were issued as soon as the delayed onset of œdema was understood. Mustard gas cases form a complete contrast, for symptoms are delayed in onset, and it can do no harm to a patient to walk down from the fire trench and subsequently be transported as a " sitting " case in the early period following exposure. The caution with which a lung irritant case must be treated from the first need not be exercised in the mustard gas case at this stage. Later on, however, when the question of evacuation to the base arises, an equal amount of caution has to be exercised in deciding on the mustard gas case, for a journey undertaken in the early stage of the secondary broncho-pneumonia may well prove fatal. In the first experiences with mustard gas this was not understood, and the general instruction that all gassed cases were to be treated as lying cases created a situation of great difficulty, for the transport on stretchers of this great mass of casualties imposed an enormous strain on the bearers. Equally the lack of knowledge of the serious late broncho-pneumonia resulted in many men being despatched to the base at the time when this sequela was commencing, with disastrous results in some cases. Subsequently, orders were framed so that the type of transport and the necessity for stretcher carriage were determined by the nature of the gassing, and in mustard gas cases evacuation to the base was postponed in all cases where a rising temperature, slight in itself, was suggestive of pneumonia ensuing. This was a sound principle on which to work, but its success depends on the knowledge possessed by the medical officers in all the echelons from front to base and their ability to decide the nature of the gassing, either from symptoms or from information obtained from the combatant or the gas services.

In addition to the " early acute " cases, a few of the " slight " cases may need to be treated as " lying " cases, as both chlorarsines and lachrymators may cause general toxic symptoms sufficiently severe to necessitate this. Speaking generally, however, it may be stated that experience proved that, whilst all lung irritant cases required to be handled as lying cases from the start, the remainder could, in the great majority of instances, go as walking or sitting cases in the first stage.

The importance of early treatment, at any rate for the lung irritants, can hardly be over-estimated, and the conflicting claims of evacuation and of treatment raise a problem by no means easy to decide. Treatment must naturally be subordinate to the military situation, but in stationary warfare it should be possible for treatment to be commenced in the trenches and to be continuous until the emergency has passed. The paragraph already quoted from the German official pamphlet illustrates the difficulty which confronted the enemy equally with the Allies.

Organization for the Treatment of Gas Casualties.

The British system of handling all casualties was the establishment of a chain of medical units extending from the regimental aid posts through field ambulances and casualty clearing stations to the base hospitals. Theoretically, every link in the chain was supposed to be capable of treating every type of wound or disease. But whilst the necessity for specialists for surgical work was early recognized to be essential in casualty clearing stations and base hospitals, the claims of medicine were longer in receiving equal recognition, for it was not until late in 1917 that a medical officer with special qualifications as a physician was officially appointed to each casualty clearing station. By this time the increase in the number of gas casualties had become so great that a definite and growing percentage of battle casualties, in addition to the ordinary sick, was passing into the medical rather than the surgical side of the field medical units. The urgent medical problems raised in the treatment of gassed cases were therefore ultimately faced by men who were for the most part qualified to attack and solve them.

The efficient treatment of gassed cases could be attempted on two separate systems. On the one hand, every medical unit might be instructed in methods of treatment and expected to be in a position to apply all necessary remedies. On the other hand, specified units, whether of a division, a corps, or an army area, might be detailed for the reception of all gas cases, and in them be collected the most highly trained personnel and the bulk of the required apparatus. Each system had its advantages and its disadvantages. For stationary warfare the method of segregation would probably be preferable. But this system had its drawbacks in heavy fighting with many casualties, or when the fighting became one of movement. Segregation of cases then became impossible, and attempts to carry it out only led to confusion, with evacuation following various routes, often across main lines of transport, with the difficulty of detailing transport for particular cases, and with the probability that even if these difficulties were surmounted the specified units quickly became crowded out. Medical units which were inexperienced in dealing with gassed cases would consequently be obliged to take over suddenly the reception of these cases, quite probably with insufficient equipment for dealing with them, at a time when they were fully occupied with other cases.

In the British service a detailed and specialized arrangement was not employed. It is true that frequently a division made one of its field ambulances responsible for receiving all gas cases, or, on a restricted front, a field ambulance received for a corps. Also, when casualty clearing stations were grouped, one would act as a gas centre for the group.

In quiet periods the principle of segregation proved successful, both for facility of working and for obtaining the best results in individual cases, just as the method was found to work well in other types of casualty, such as wounds of the abdomen or thorax. Whilst this experience applied more particularly to field ambulance administration, it was much the same in the case of the casualty clearing stations.

When formations were stationary for some sector in a time this arrangement worked smoothly and efficiently, but when divisions were perpetually on the move and the constituent units of a corps constantly changing, or when the line advanced, it could not so well be carried on and all segregation had to be abandoned.

The simplification of the routes followed by the motor ambulance convoys was essential to rapid working in " rush " periods, and detailing of cars for special service to a particular casualty clearing station led to delay and confusion. Moreover, the " switch " system of working grouped casualty clearing stations gave better results in the aggregate, as, having received a definite number of cases, no more admissions were made until the remainder of the group had received their share. This gave opportunity to classify and deal with cases more thoroughly, an advantage which was lost when the unit had to receive continuously.

It was, therefore, accepted as a necessity that in the army zone each medical unit should contain amongst its personnel enough of all ranks adequately trained, and at any rate a small amount of equipment, for the treatment of gassed cases.

Summarizing the experience as to the value or otherwise of specialist treatment in the field, it may be stated in general terms that such treatment is of value in quiet times, both from the point of view of the individual case, and for the purpose of training medical personnel in the best methods of handling cases. When active operations are in progress this system cannot be carried on, certainly not in the field ambulances, and with only limited effect in the casualty clearing station zone. Experts, who may have been collected in the special centres, must then be redistributed to their own units, and it must be the aim of medical administration to maintain a general standard of knowledge and efficiency in all units, rather than to promote individual excellence.

Whilst this broad statement holds good for the army areas, it must not be taken as applying in its entirety at the bases. There, other factors come into operation, more particularly the questions of invalidism and duration of convalescence.

The base should always contain a group of medical officers attached to some specially chosen hospitals and convalescent depôts with the duty of controlling and reporting upon the treatment of gas casualties. So far as possible the main mass of gas casualties should be diverted to these special hospitals, so that accurate knowledge may be collected with regard to the best methods of treatment and to the times of invalidism that should be expected in handling casualties from any particular poison gas. Information can then be given to medical officers in those other hospitals in the area which will, in times of pressure, also be required to deal with the overflow of gas casualties from the special units. Arrangements of this nature were made locally at the Boulogne base, and they proved of great value in supplying the medical services and the gas directorate with needed information.

For longer invalidism of the severer cases in hospitals in the United Kingdom it was still more important that special organizations should be detailed. Most of these cases soon recovered sufficiently to be transferred from the central hospital to auxiliary hospitals or to command depôts. They were scattered widely over the country and came under the care of medical officers who naturally were uninstructed and inexperienced in the handling of gas casualties. The record on p. 515 of the long times of invalidism spent by mustard gas casualties who had been transferred from France to the United Kingdom will sufficiently illustrate the wastage of man power and the unnecessary burden on the medical services that resulted from the reluctance to establish special centres in England for dealing with gas casualties.

French Organization for Gas Casualties.

The French, recognizing the great value of specialized organization for achieving the best possible results with gas casualties, built up in the late period of the war an elaborate system of special medical units for gassed cases which was designated the "Z" system. These were established by an order dated 16th July 1918, and in consequence they did not exist long enough to have their practical utility tested in heavy fighting. This system developed from an organization of gas centres, which had been introduced at the end of 1917, and which was communicated by the D.G.M.S. to the Ds.M.S. of the British Armies in January 1918 with a view to their imitating it.

The French "Z" system was as follows :—

(1) *Regimental Aid Posts.*
  (*a*) Bathing and change of clothes for mustard gas cases (rarely possible).
  (*b*) Urgent treatment of phosgene cases.

(2) *Lavage post of divisional stretcher bearer groups.*
  (*a*) Prophylactic lavage by hot-water douches of men who have been exposed to mustard gas, but exhibit no symptoms. Disinfection of clothing, each man receiving his own clothes back again.
  (*b*) Lavage and changing of clothing of mustard gas cases.

(3) *Corps "Z" ambulance.*

One of the two corps ambulances is designated as "Z" ambulance.

Medical staff :—
  1 senior M.O. in charge.
  2 M.Os.
  Corps ophthalmologist.
  Corps ear and nose specialist.
  Same personnel as other ambulances.

Sub-divided into :—
  (*a*) Sorting and observation station.
  (*b*) Hospital station.

Equipment :—
  Hot-water douches for lavage.
  Disinfector for clothing.
  Tent or hut accommodation with 100 to 300 beds.
  Oxygen apparatus.
  Supply of clothing.

Any cases of mustard gas poisoning that have not been bathed at the lavage post of the divisional stretcher bearer group are bathed on arrival at the "Z" ambulance. Cases are classified. The mild cases are sent to the observation wards and retained, so far as possible, till fit for duty. If the observation wards are full, cases are passed on to the army "Z" ambulance, or failing these to hospitals on the lines of communication. The severe cases are retained in special wards till fit for evacuation. The "Z" ambulance may in addition have to sort out corps sick and treat the non-transportable cases.

(4) *Army " Z " ambulances.*

Derived from the available corps " Z " ambulances in the army, and have the same medical personnel and equipment. Their function is to supplement the " Z " ambulances allotted to corps, and they are placed on the lines of evacuation, either in or near the casualty clearing stations. The army ophthalmologist and the ear and throat specialist should be in close touch with these units if no such specialists are carried on their strength.

The general principle is to arrange the corps and army " Z " ambulances in echelon, so as to be able to cope with a very large number of casualties.

(5) *" Z " hospitals on the lines of communication or in army zones.*

These should have 500 to 2,000 beds. Situated on evacuation routes and easily accessible by train.

They comprise :—

(*a*) Observation station.
(*b*) Complete hospital accommodation, with isolation wards for cases of pneumonia, facilities for treatment of severely burned, etc.

So far as possible, an ophthalmologist, an ear and nose specialist and a dermatologist should be included in the medical staff. They may be formed from a group of " Z " ambulances or from a " Z " complementary hospital.

Mild cases that overflow from " Z " ambulances are received and retained in the observation wards. Severe cases are admitted as soon as they can be evacuated from the " Z " ambulances and are treated in the hospital section. Great stress is laid on the fact that observation stations (*i.e.*, the places where mild cases are treated), no matter how far from the front, should remain under the army control and not under the control of the authorities in the interior of France, so as to minimise unnecessary wastage.

In order that the different " Z " formations may supplement one another efficiently, there must be the closest liaison between the different echelons.

Special gas hospitals for the treatment of severer cases evacuated from the army areas, were also established in the interior of France, and a large one in Paris was especially used for the study of the progress and treatment of these invalids.

American Organization for Gas Casualties.

The American system was not evolved as a result of American experience in the field, with a yearly increasing number of gas casualties, but was planned from a careful study of the experiences of the French and British armies and then laid down on a broad scheme, which should be ready at once for adaptation to the large number of gas casualties that were expected when the troops went into action. In its acceptance of specialization it was very similar to the system finally adopted by the French.

The medical organization was entrusted to an officer on the staff of the Chief Surgeon and known as the Medical Director of Chemical Warfare Service. He acted as liaison officer between the Chief Surgeon and the Chief of the Gas Service. To each division was assigned a divisional medical gas officer, whose duties were to instruct all officers and men in the symptoms and early treatment of gas poisoning, to train medical personnel in the methods of gas treatment, to supervise methods of gas protection in medical units, and to train the men of these units in the principles of handling gas casualties.

Special medical units were detailed to receive and treat gassed cases. In each division one of the field hospitals was designated a mobile gas hospital and was equipped with additional apparatus and had its personnel augmented by specially trained men. Such a gas hospital had 100 cots for serious cases.

Each corps had allotted to it three mobile gas hospitals, each of 1,500 beds capacity and operated under the plan of evacuation hospitals.

A further unit was that known as the " motorized mobile degassing plant," of which it was contemplated to provide two for each division. At the time that the Americans entered the field in force mustard gas had become the main gas problem, and it was to deal with masses of casualties or of men exposed to this agent that the degassing plant was devised. It consisted of a motor lorry carrying a tank with a capacity of 1,200 gallons of water, a pump for filling the tank, and a heating device for warming the water. It also carried the bathing apparatus consisting of a framework supporting twenty-four shower sprays, which could be connected up to the hot water tank. A 3-ton lorry carried a portable tent in which to instal the baths, and spare clothing and equipment sufficient to re-clothe and equip 500 men.

It was claimed that such a plant could bathe twenty-four men in one and a half minutes, and that, provided the water supply was ample, there was no limit to the number of men who could be handled. The water carried in the tank was sufficient to bathe 700 men. The uses of such a plant were not confined to degassing, as it was also found invaluable in the ordinary routine of bathing and delousing the troops.

The American organization was essentially a specialized one, with the advantages and disadvantages necessarily associated with specialism. Whilst theoretically such a service would appear ideal, it is by no means certain that in the stress of a general action it gave the results that a less highly specialized organization would have achieved.

German Organization for Gas Casualties.

The German organization for gas casualties was not fully known during the war. It appeared to be based partly on the general idea governing all their medical organization, namely, that relatively light casualties should be retained in army areas until fit again for duty, and also on the acceptance of a certain specialization in the use of units detailed for gas cases. The following rules were in operation in the German medical service at the end of 1917 :—

(1) " Alleged " cases of gas poisoning and malingerers who show no definite symptoms are retained for twenty-four to forty-eight hours for observation in medical inspection rooms of units, bearer companies or field hospitals, or in collecting stations for mild cases, with a view to returning them to their units if possible. They are not admitted at once to local or field hospitals, nor to gas casualty stations.

(2) Cases showing definite objective signs of gas poisoning are transferred to a gas casualty station (Gaskrankenstation) with specially trained medical officers and nursing staff. Such gas casualty stations remain semi-permanently in the sector, and retain their trained personnel. The medical officers and trained personnel may be detailed for temporary duty in hospitals that have no gas casualty station attached, if these units admit a large number of gas cases.

(3) There is a special convalescent depôt in each army to which gas cases may be sent for several weeks before rejoining their units after three to four weeks' hospital treatment.

General Treatment of Gas Casualties.

The handling of cases must now be considered from the point of view of :—

(*a*) Nature of gas.
(*b*) Individual severity.
(*c*) Number of casualties.

Bearing in mind the classification already laid down, it is clear that the pressing problem of the lung irritant is early treatment, that of mustard gas is to remove contaminated clothing and to prevent secondary infections, whilst for the other groups it is mainly one of temporary accommodation and prevention of unnecessary wastage.

Lung Irritants.—Experience showed that early treatment might be summarized as rest, oxygen, venesection. Rest was obtained by stretcher carriage throughout, and by careful nursing. The latter being such an important factor and only obtainable in full in the casualty clearing station, every effort was made to get these cases back to a casualty clearing station with as little delay as possible. In quiet times this was usually done by running the cars of the field ambulance direct from the advanced dressing station to the casualty clearing station or special gas centre, without passing through the main dressing station. During heavy fighting much the same result was attained by the system, first introduced for gassed cases in the Passchendaele fighting in 1917, of carrying out all the record work at the casualty clearing stations, the field ambulances sending their clerks there.* In this way valuable time was saved and unnecessary interference with the patient avoided.

Where delay arose in clearing the aid posts, often inevitable owing to difficulties of evacuation, it was necessary to supply them with oxygen and means of treating by venesection. Once pulmonary œdema was established transportation added very seriously to the patient's risk, though early venesection beforehand and continuous oxygen administration throughout the journey were of invaluable assistance. It, therefore, became the practice to advise medical officers that venesection should be performed where cyanosis was present, before evacuating the patient. The shortage of the oxygen supply, the weight of the heavy cylinders and the frequent loss of the cylinder keys and attachments were very material difficulties militating against the widespread use of oxygen. Unfortunately, the light field pattern of Haldane's oxygen apparatus was not available until the very end of the war. The general issue of that apparatus to regimental medical officers and field ambulances, together with the feather weight, high tension steel oxgyen containers, practically solved the difficulty of oxygen supplies in the trenches, and made possible the continuous administration during transport, even on stretchers in the trenches. Given an adequate supply of oxygen, as was practically arranged for in the later stage of the war, sufficient provision would have been made for the immediate treatment of these cases.

In the days when the supply of oxygen was difficult to maintain, it was usually necessary to keep the available cylinders collected largely at specified casualty clearing stations and to get the cases back with all possible speed without carrying out any treatment further forward, beyond loosening clothing and giving inhalations of ammonia. Particularly so was this the case in the Ypres salient, the area so frequently gassed, for the aid posts and advanced dressing stations offered little protection and gas-proof dugouts were frequently impracticable.

At the casualty clearing station or specified field ambulance gas centre more elaborate preparations were needed. The first essential was suitable accommodation. The idea was largely prevalent that these cases should be treated in the open air, or in tents with flies down. Whilst an abundant supply of fresh air is highly important, it is equally necessary to provide for warmth, adequate lighting and nursing facilities. The element of profound shock enters largely into the symptoms of acute gassing, and warmth was the quickest and most reliable method of treating shock, as experience with wounded showed. Adequate illumination was necessary to detect slight cyanosis, and also to determine the quantity of oxygen needed. A well-ventilated, well-lighted and well-warmed building, such as many schools provided, was far preferable to tents as a ward for the serious cases, except possibly in the heat of summer.

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* This system had been used for ordinary casualties in previous battles, as for example for casualties of the VIth Corps during the battle of Arras in April 1917.—E.-in-C.

In a well-organized gas centre cases were classified on entry, according to severity of symptoms. The acutely affected were transferred directly to wards where oxygen apparatus was installed, whilst those in whom serious symptoms might supervene later were kept in an adjacent ward. Those in whom no signs or symptoms were apparent were kept in observation wards. Experienced medical officers quickly learned to classify these cases on admission, and were rarely mistaken in recognizing cases where an acute phase might be expected. Whenever a material dose of gas had been inhaled, some objective signs were always present and could be detected by the trained eye.

The value of oxygen in treating pulmonary œdema has been constantly referred to. Captain Adrian Stokes devised a distributing apparatus, by which many men could be simultaneously treated. A lead from the cylinder was taken to an oil drum, which acted as a pressure reducing chamber, and from this several rubber leads branched off to nozzles which could be taken to the bedside, each being controlled by a stop-cock. In some casualty clearing stations the method was developed so that the gas ward was fitted throughout with lead piping having nozzles over each bed, and a continuous supply of oxygen could then be delivered.

An ingenious device was employed at one field ambulance gas centre near Bailleul to enable patients already gassed to have oxygen continuously, even if a wave of gas reached as far back as the gas centre. This was the provision of a number of small box respirators, to the bottom of the boxes of which nozzles were affixed. On these nozzles rubber connections communicating with an oxygen delivery pipe could be clipped, and thus, when the face-piece was adjusted, the patient could receive a supply of oxygen through his mask.

The introduction of the Haldane apparatus, supplied at first with four delivery taps and subsequently with one, overcame most of the difficulties of administering oxygen, and also was a great economizer, for oxygen was only flowing during the patient's inspiration. This apparatus revolutionized the oxygen treatment, simplifying the administration, and was so easy to work that an orderly could be trained to handle it satisfactorily.

A gas centre as understood in the light of experience, should, therefore, contain well-lighted, well-warmed wards, suitable for acutely ill and profoundly shocked patients, with ample oxygen-delivering apparatus, venesection and transfusion sets accessible, and an adequate staff of nurses and orderlies capable of recognizing the first danger signals and fully alive to the necessity for complete rest on the part of the patient.

The right time at which to evacuate cases to the base was not appreciated until the delayed onset of œdema was fully understood. As a precautionary measure, cases in whom such a complication might arise were ultimately retained for at least forty-eight hours, and were then evacuated as lying-down cases. For those recovering from a more acute phase, the criteria of pulse, respiration and temperature were applied, and of these the pulse was regarded as the most reliable sign. Recovery was always signalized by a definite bradycardia, and until this was present it was wiser not to evacuate. The cases which developed broncho-pneumonia were those where delay in moving was most prolonged.

At the bases no special preparations were made for gassed cases until lung irritant cases had become a negligible number. The arrangements for the segregation of cases which came into force for mustard gas casualties would, however, have applied with equal force to other types of gas. The rules for evacuation to the United Kingdom were on the same lines as those applying to transference from the casualty clearing station to the base. In the early days nearly every gassed case was sent home, a practice which resulted in unnecessary wastage, as many could have been adequately dealt with in convalescent depôts.

Mustard Gas.—The vapour or finely divided fluid which was scattered widely on explosion not only directly affected men, but also contaminated everything with which it came into contact, and in the slow process of evaporation continued to affect both the patients and those dealing with them. This was quickly recognized, and it became a routine to remove the clothing as early as possible. Not only had clothing to be removed, but an attempt had also to be made to wash the whole of the skin of the patient in order to remove any poison which still remained on the body, and to limit, as far as possible, its effects. This necessitated the establishment of bathing centres, with an ample supply of warm water. Further, the eyes required early treatment, frequent and copious lavage of the conjunctival sacs being the best method of alleviating pain and reducing inflammation. Administrative problems of magnitude and complexity were thereby introduced, and it can hardly be claimed that an adequate solution had been found before the close of the war. More particularly was this the case when the war became mobile, and troops advancing over contaminated ground, often far in front of their medical units, which were themselves constantly on the move and unable in consequence to erect proper bathing facilities, ran the risk of having both themselves and their clothing contaminated with the gas.

As regards the immediate medical treatment of casualties, unceasing efforts were made to find an antidote which would neutralize the effects of the poison ; but no real success was obtained. Once the man had been definitely exposed, either to the vapour or to the mustard gas in its fluid form, lesions inevitably resulted, and no neutralizing agent could "catch up" and suppress entirely the toxic action. A slight preventive value was attributed to the immediate use of bicarbonate of soda, whether applied in the powdered form to the skin or as a 2 per cent. solution to the eyes. Chloride of lime was also largely employed, mainly, however, for neutralizing the contamination of guns and articles of equipment. Gunners who contaminated their hands by handling splashed articles were able, if they applied the chloride of lime immediately, to ward off or minimize the burns.

The main difficulty experienced in dealing with mustard gas cases was to decide on the best spot to establish treatment centres. Obviously, the farther forward cases were treated the better the result obtained, for, so long as a man remained in his contaminated clothing, he was continuously exposed to further inhalation of vapour. In practice, it was the rule to remove obviously contaminated clothing in the regimental aid post and to send the man down wrapped in blankets. The less obvious cases were sent direct to a gas centre, where proper bathing facilities were available. Such a centre was of necessity some way back in order to avoid being constantly shelled. It was no small task, particularly in winter, to arrange for a sufficient supply of hot water at all times.

Patients were admitted to a warm receiving tent, where they stripped and passed their clothing through a swinging flap into a large receptacle outside the building. They then passed into the bathing shed, where either tub-baths or shower-baths, with plenty of soft soap, were ready. After thorough bathing they were drafted to wards, where routine irrigation of the eyes with 2 per cent. soda bicarbonate solution was carried out. According to the severity of the case individuals were then either retained for treatment until well, sent to a casualty clearing station, or evacuated to the base. The American degassing plant already described was devised to carry out this treatment on a wholesale scale.

The difficulty frequently experienced was to ensure a supply of clean clothing. Whilst the divisional or area laundry could usually supply sufficient underclothing in exchange, it was far less easy to obtain outer clothing and equipment. Divisional ordnance stores were not equal to wholesale renewals from their limited stock, and in the case of casualty clearing stations, dependent either on an army or a corps ordnance store, the difficulty was even greater. Clothing only lightly contaminated as by vapour could be re-issued after it had been exposed freely in the fresh air, particularly in the wind, for not less than forty-eight hours. During this time the patient, whose clothing was so treated, was obliged to remain in bed. Clothing that was obviously splashed could not be successfully treated in this way, and experiment showed that it required far more prolonged methods.

In factories in the United Kingdom definitely contaminated clothing was placed in spirit for five minutes, then dipped in a small volume of very hot water. This was a very rapid method. It was estimated that three or four litres of spirit for the clothes of each person were required. The details of the spirit treatment are as follows :—

The clothing is placed in a methylated spirit bath at a temperature of 60° C. (140° F.) for five minutes. Hot water (80° C. or 176° F.) is then run into the bath to bring the volume to five or six times the original. This is allowed to stand for ten minutes. The liquid is then run off and the clothes finally washed in cold running water for thirty minutes. At this stage a handful of washing soda can be added beneficially and without injury to cloth, but it is not essential if running water is used for the final washing. The clothing is then dried.

Another method of treatment was by a solution of Turkey red oil (5 per cent.), sodium bicarbonate (4 per cent.), in water at 20° C. The clothes were moved about vigorously in this solution for one hour, then washed in plain water and dried in the open air.

Another effective treatment was hot water (about 85° C. or 185° F.) containing 0·5 per cent. chalk, in which the clothes were left for an hour. This method required closed vessels. Steam treatment of the clothing in a Thresh disinfector or delousing shed was also effective.

Chlorine gas was also found to be an excellent neutralizing agent. At the termination of the war experiments were in progress to devise a portable apparatus in which heavily contaminated clothing could be hung and exposed to chlorine vapour, but they had not reached a satisfactory conclusion. Further, in the process of neutralization, clothing which had been grossly contaminated by splashing was ruined, owing to the fabric being destroyed by the hydrochloric acid formed.

The British, French, and American armies used chlorine as a neutralizing agent when the clothing was but slightly contaminated. Air-tight chambers were provided, and men who had been exposed to mustard gas entered these chambers wearing their masks and were then exposed to a concentration of chlorine of one part in one thousand of air. It was found best to burn grossly contaminated clothing, and to depend on fresh air, particularly air in motion, or the chlorine chamber, for the lesser contamination. Underclothing, after thorough airing, was sent to the laundry and made safe for re-issue.

All men who were employed in undressing patients or in handling their clothing always wore masks, respirators, and oiled leather gloves. In some instances also rubber or jaconet aprons were issued to them.

The provision of bathing facilities and of fresh clothing was all that was needed for the light cases, which could be returned to duty from the forward centres. For the more severe cases hospital treatment was necessary and was provided in the casualty clearing stations. A certain number of men developed a severe conjunctivitis, burns, or serious respiratory affections, necessitating a prolonged period of invalidism. The danger of evacuating these men to the base at the time when respiratory complications were developing has already been mentioned. Evacuation to the base had, therefore, to be carried out very shortly after exposure, or to be delayed until all danger of broncho-pneumonia supervening had passed.

The capacity of the casualty clearing stations was an important factor in the decision. If this was not strained, it was found advisable to retain cases until the conjunctivitis had yielded to treatment and respiratory troubles were no longer to be feared. If the casualty clearing stations were greatly congested it was often necessary to evacuate cases early, trusting to the personnel on the trains being able to carry on the treatment for eye and skin lesions, but insisting that all original kit should be changed before entraining.

Once a case had developed a rise of temperature, even slight, it was never wise to hasten evacuation, as this sign almost invariably was the indication of a commencing acute bronchial infection.

Arsenical Warfare Gases.—In this group of cases the problem of treatment was comparatively simple. As has been pointed out, cases of lasting severity were extremely uncommon. Troops subjected to a heavy Blue Cross bombardment suffered from a considerable number of casualties which at times strained the resources of the forward medical units. Provided there was sufficient accommodation for the retention of these cases in the army area for a matter of four or five days, evacuation was rarely necessary.

So transient were the effects that practically only the cases, very small in number, which showed those marked nervous manifestations such as anæsthesia and paralysis which are described elsewhere and which are to be regarded as functional in origin, required treatment at the base.

Handling of Gas Casualties at the Base.

The problem of handling gas casualties at the base was essentially that applying to all other types of casualty, namely, the retention of all men who were likely to be fit to return to duty within a reasonable period, and the evacuation to the United Kingdom only of such cases as would require a long period of hospital treatment. Unfortunately, it was not sufficiently realized until the later stages of the war that the recovery rate of gassed casualties was remarkably good and that once the initial stage had been passed convalescence was, in the majority of cases, rapid.

The value of specialist treatment of types of cases applies with greater force to the base organization than to that in the forward areas, and there is more opportunity in the comparative leisure of the base to segregate, to classify, and to study the individual case.

The selection of definite hospitals at some bases for the reception of gassed casualties led to a very considerable improvement in the handling of these cases, both in individual treatment, and more especially as regards the prevention of wastage to the United Kingdom.

When the principle of segregation was adopted at the base and selected medical personnel were given the opportunities to study on a broad scale the treatment and the after-effects of gassing, wastage was rapidly reduced.

There were remarkable divergencies in the disposal of cases at the various bases, indicating that control of wastage was not carried out on a uniform basis. The facts are shown in the following tabulated analysis of the disposal of gas casualties during certain periods in 1918. Officers are excluded because no facilities on a large scale for their treatment in convalescent depôts were provided in France.

Disposal of Gas Casualties from different Bases.

1918.	Boulogne	Etaples.	Rouen.	Total for all Bases.
Week ending 19th March :				
Admissions	619	1,384	2,631	6,607
Deaths, per cent.	1·2	1·4	1·1	1·1
Percentage to U.K. on disposals	67·0	80·0	82·0	78·0
Week ending 16th April :				
Admissions	1,615	2,903	1,646	6,504
Deaths, per cent.	1·2	0·6	1·0	0·8
Percentage to U.K. on disposals	30·0	62·0	71·0	55·0
Week ending 14th May :				
Admissions	911	401	1,533	3,373
Deaths, per cent.	1·4	4·5	14·8	9·0
Percentage to U.K. on disposals	24·0	49·0	75·0	55·0
Four weeks ending 12th October :				
Disposals	3,531	1,436	4,004	13,956
Deaths, per cent.	1·1	0·5	1·5	1·25
Percentage to U.K.	20·2	62·0	45·0	34·3
Four weeks ending 9th November				
Disposals	2,837	2,498	3,373	10,550
Deaths, per cent.	1·2	1·6	2·3	1·7
Percentage to U.K.	16·0	58·0	30·0	33·0

During the above period admissions to the Boulogne base for gas casualties were about 25 per cent. of the total admissions for actual wounds in action.

The differences noted in the statistics for the various bases were in part to be explained by differences in the total accommodation at convalescent depôts provided at each base in relation to the number of hospital beds. The value of the convalescent depôt in treating the late stages of gassing equally with the late stages of all other minor sickness or minor casualties can hardly be over-estimated. An efficient convalescent depôt was a great saving of man-power. The recognition of the fact that a very minor ailment may yet so reduce a man's resistance as to render him unfit for active service led to the establishment of centres where moral and physical tone could be restored by means of healthy exercise, generous diet, and plenty of amusement. It is probable that for every hospital bed in a base, two beds in convalescent centres could be usefully employed. This applied perhaps with greater force to gas casualties than to any other class, for, in addition to the physical injury, often slight, the trauma sustained by the nervous system was very considerable, and was no doubt responsible for much of the functional after-effects.

A certain small percentage of cases required to be evacuated to the United Kingdom owing to the severity of their lesions. The after-progress of the cases was not so satisfactory as it might have been, largely owing to the fact that medical officers in home hospitals were not fully conversant with the facts as regards gas warfare and the right method of treatment of casualties resulting therefrom. The policy of secrecy which undoubtedly was necessary from the military point of view in the early stages reacted injuriously on the medical services. There is little doubt that this ignorance as to the normal times of recovery in the various types of gas poisoning, led to men being retained for an unnecessarily long time in hospitals at home. The fact that functional disorders were frequently grafted on organic lesions and promoted a prolonged invalidism was not sufficiently recognized.

Evidence with regard to the unduly long time for convalescence in the United Kingdom appears in the analysis undertaken by Meakins and Priestley to which reference has already been made. This report dealt with 4,575 cases discharged from primary hospitals during the summer of 1918. The cases were received in England at a time when the percentage of evacuations from France was at least twice as high as it should normally have been, and therefore fully half of the 4,575 cases must have been of the lighter type, which in France could be returned to full duty in two months.

28·5 per cent. of these cases, or 1,285, were discharged to their reserve battalions, chiefly in the fourth to seventh week; 33 per cent., or 1,505, went to command depôts, chiefly in the sixth or seventh week; 33 per cent., or 1,502, went to military convalescent hospitals, chiefly from the second to eighth week.

The total time of convalescence in the United Kingdom for cases of moderate severity was estimated by analysing the facts with regard to another 450 gassed cases seen at a reserve depôt. Their average stay in hospitals, primary and auxiliary together, had been six weeks. In convalescent hospitals and command depôts the average stay had been an additional six to eight weeks. The majority had been returned as fit for full service at some time in the third or fourth month, but 25 per cent. had taken over six months to attain this fitness. In another analysis made by Colonel A. B. Soltau in May 1919, of a series of 75 cases still under treatment in military hospitals for gas poisoning, 36 mustard gas cases were finally discharged fit for duty after an average stay in hospital of 167·5 days, the longest stay being 356 days and the shortest 93 days. These cases all gave a history in which nervous and functional symptoms predominated. Of the 39 cases invalided for gas, 26 were invalided for respiratory trouble, 5 for neurasthenia and debility, 2 for gastritis, 5 for disordered action of the heart, and 1 for corneal ulcer, the average stay in hospital of these 39 cases being 289 days.

It appears likely that, for lack of skilled knowledge and experience in treatment, mustard gas casualties were allowed to remain in hospitals nearly a month longer than was necessary and equally a month longer in hardening at command depôts. To all this delay had to be added the extra time unavoidably spent in getting the soldier overseas again to active service. It was therefore a matter of great importance in lessening wastage from gas casualties that such casualties, so far as convalescent depôt accommodation permitted, should be retained in France under a system of treatment strictly supervised by officers with special knowledge of gas poisoning.

The total admissions to lines of communication hospitals for mustard gas poisoning were over 120,000. During 1917 nearly 60 per cent. out of 34,715 were transferred to the United Kingdom, that is probably 10,000 men in excess of what need normally have been transferred. Similarly for 1918, though the exact figures for analysis are not available, it is probable that 25,000 relatively light casualties were transferred to the United Kingdom. The aggregate wastage on 35,000 patients who were returned to active service perhaps two or three months later than they might have been was therefore considerable ; and the wastage would have been far higher if it had not been for the administrative measures to check this wastage which were devised as the result of accurate information obtained by statistical studies of clinical results at certain hospitals specially set apart for gas cases.

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CHAPTER XVII.

INVALIDISM FROM GAS POISONING.

THE permanent effects of gas poisoning can be gauged by knowledge of the pensionable disabilities arising from them. Unfortunately, however, it is impossible to distinguish in the records the precise type of gas by which each casualty was originally caused.

The following analysis of information supplied by the Ministry of Pensions shows the general character of the more protracted disabilities seen after gas poisoning, without distinction of the particular form of gas.

During the twelve months period, August 1919–1920, the resurvey boards made 26,156 examinations of cases of gas poisoning. Many of these men were examined more than once during that period, and the total number of individual cases examined is calculated to have been about 22,000. But of this number 3,136 were at once classed as " *nil*," since they showed no disability, leaving the total number of pensioners as about 19,000.

The known total of gas casualties in France is shown in Table I.

TABLE I.

Summary of total Gas Casualties in France from the commencement of Gas Warfare till the close of the War.

	Total Gas Casualties.	Total Deaths.
Cloud attacks with chlorine, April and May 1915	7,000*	350*
Lachrymator gas shell, May 1915–July 1916 ..	?	*Nil.*
Cloud attacks, December 1915–August 1916 ..	4,207	1,013
" Lethal " gas shell, July 1916–July 1917 ..	8,806	532
Gas shell, July 1917–November 1918. Mustard gas period.	160,526	4,086
Projector attacks, December 1917–May 1918 ..	444	81
Total	180,983	6,062

* Approximate figures for casualties admitted to medical units only ; many casualties died on the field or were taken prisoner.

Surviving cases, excluding the few late deaths in England, therefore aggregated 174,921. But many of these were men who were gassed more than once, on each of which occasions a fresh casualty would be reported. It is impossible to determine the proportion of these; and the number of survivors from the early chlorine attacks is also unknown. As a reasonable approximation one may accept 150,000 as the total number of individuals surviving after gas poisoning, many of whom were, of course, very mild cases.

The number receiving disability pensions in 1920, two or more years after gassing, was approximately 19,000, that is, about 12 per cent. of the total gas casualties. Gas poisoning was responsible actually for 2 per cent. of all the disabilities after the war, 35 per cent. of all pensioners being classified as suffering from wounds and injuries, and 65 per cent. as suffering from diseases.

The percentage degree of disablement from gas poisoning was generally low. Table II shows the actual assessments in a consecutive group of 2,416 examinations made by boards in a period of four weeks during September 1920.

TABLE II.

Disability Assessment.	Number of Cases.	Percentage of Total.	
100 per cent. disablement	12	0·49	=3·15
90 ,, ,,	—	—	
80 ,, ,,	3	0·12	
70 ,, ,,	11	0·45	
60 ,, ,,	12	0·49	
50 ,, ,,	39	1·6	
40 ,, ,,	106	4·3	
30 ,, ,,	387	16·0	
20 ,, ,,	840	34·7	
Less than 20 per cent.	720	29·8	
Nil	286	11·8	

Excluding "*nil*" assessments, the average degree of disability assessed was approximately 20 per cent. The figures show clearly that very few men were seriously or totally disabled. A case of severe shortness of wind from bronchitis or emphysema would be assessed at nearly 100 per cent., and so, too, would a case of pulmonary tuberculosis. It is therefore evident that such serious after-results were rare, and that the ailments complained of were generally of a very light character. Colonel A. B. Soltau examined in March 1919 the documents, but not the patients themselves, in a series of 150 gas pensioners who were selected as being of a more serious nature than the average, and he grouped their disabilities under the following clinical headings :—

Non-organic diseases—	
Neurasthenia	30 per cent.
D.A.H. and debility	25 ,,
Pulmonary diseases—	
Bronchitis, asthma, etc.	35 ,,
Tuberculosis	4·5 ,,
Other diseases—	
Valvular disease of the heart	4·5 ,,
Other complaints	1 ,,
	100

The group is too small for close statistical argument, but in considering it attention should be given to the fact that valvular disease of the heart was found by the Ministry of Pensions to have been responsible in 1919–1920 for 6 per cent. of all diseases, gassing being included among diseases for this purpose, and pulmonary tuberculosis for 5 per cent. of all diseases among pensioners. The percentage is therefore much the same for gassed and for non-gassed men. If this similarity is used to explain the incidence of valvular disease of the heart in gas pensioners, an organic disease which has never been ascribed to gas poisoning, then it must also be admitted in the case of pulmonary tuberculosis. But a rigid comparison cannot be made on these figures. What is needed for that purpose is a knowledge of the percentage incidence of pulmonary tuberculosis among casualties from ordinary wounds and from gas respectively, and that analysis has not been made.

In the total number of all pensioners there were 4,351 deaths recorded at a date near the end of 1920. Gas poisoning was named among the various causes of invaliding disability in fifty-nine of these deaths. An examination of the card records of the cases that had died yielded but scanty information, for in most instances the actual cause of death was not certified. It should be noted that in only ten cases was there a clear history of even moderately severe gassing ; the rest had all been light casualties and their deaths may possibly have been quite independent of the accident that they had been gassed.

The deaths were due to :—

Pulmonary tuberculosis	13, of whom 3 had been very definitely gassed.
Bronchitis, etc.	7, of whom 3 had been very definitely gassed.
Aortic disease	4, all light gas casualties.
Nephritis	2, both light gas casualties and the nephritis having developed at least a year after gassing.
G.P.I. and apoplexy	2, both lightly gassed.

Unknown causes .. .. 31, of whom 4 had been very definitely gassed. Of the 31 there were 6 who, before death, complained of bronchitis and debility, and may possibly have been tuberculous.

Taken by themselves these last figures convey little except the proof that late deaths among gas casualties had been few up to the end of 1920. But the general conclusions that follow upon this survey of the statistics of the Ministry of Pensions agree very closely with those previously based on the statistical analysis made by Meakins and Priestley in chlorine cases and on the clinical study by other officers of groups of gas casualties in France during the war. Neurasthenia, debility, disordered action of the heart, and bronchitic attacks are the main sequelæ to gas poisoning. Few cases are seriously crippled. Pulmonary tuberculosis may be very slightly more prevalent among gas casualties than among other pensioners, but the increased incidence is trifling.

Invalidism from Mustard Gas Poisoning.

The only reliable statistics of invalidism other than those given in the previous chapters for any particular form of gas are those referring to mustard gas poisoning. The general rate of mortality from mustard gas and the times of death after exposure have already been described.

The proportionate frequency with which various organs were affected varied from time to time, being dependent somewhat on the methods of protection and on the state of gas discipline maintained, and also partly on the season of the year.

In general, and particularly in the army areas where all cases were dealt with, the returns of field ambulances indicated that in nearly 100 per cent. some degree of involvement of the eyes and the larynx was present.

The skin lesions require less consideration as a cause of disablement for they very rarely occurred alone, and prolongation of invalidism was due rather to trouble in the respiratory passages, in the eyes, and to general debility. Among 3,000 cases during July and August 1917, skin injury was present in only about 20 per cent. All except the most serious lesions were healed in less than a month, that is, sufficiently inside the general time of invalidism for these casualties.

The average period of invalidism was worked out in several series of cases. Captain Barber, R.A.M.C., at No. 25 General Hospital, Hardelot, analysed the result in 300 moderately severe cases.

These statistics refer to casualties arising from the first bombardment with mustard gas during July 1917, and they had been selected so as to include an unusually high proportion with skin lesions. Of the 210 who were discharged as "fit for duty" the period from the date of exposure to the date of discharge from convalescent depôt was as follows :—

	Percentage of Cases.
2nd week	0·5
3rd ,,	1·5
4th ,,	2·5
5th ,,	22·0
6th ,,	37·5
7th ,,	19·0
8th ,,	17·0
9th ,,	0·5

Of the remainder, 86 were at the end of the ninth week still in convalescent depôts and 13 on temporary duty at base depôts.

From the same series the following table was prepared to show the duration of invalidism according to the lesions :—

TABLE III.

Percentage of Cases Cured, by Weeks.	Weeks.								
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th
Skin..	30·0	15·0	32·0	19·0	2·0	1·0	1·0	—	—
Eyes	20·3	25·5	9·3	17·2	4·5	3·8	2·7	7·0	20·7
Pharynx	51·2	36·6	7·2	3·0	1·0	—	1·0	—	—
Larynx	52·3	33·2	7·7	5·0	1·4	—	0·4	—	—
Lower respiratory tract	17·0	42·2	25·3	9·3	2·2	1·5	1·0	1·5	—

In other series it was found that between 60 per cent. and 70 per cent. of all cases reaching the base could be cured within six weeks, and that within two months all but the small number of gravely affected cases had returned to duty. A careful study of such series is an illuminating example of how wastage could be controlled, and the period of disability of patients curtailed by a full knowledge of the probable duration of illness, and consequently by a careful control of evacuations. Had this been realized early instead of late, the aggregate of the days in hospital saved would have been very great.

Colonel Elliott, when consulting physician to the Boulogne base, prepared exhaustive statistics to show how convalescence could, with expert knowledge, be hastened. At No. 7 Stationary Hospital, two groups admitted in May–July and in August 1918 respectively were treated and analysed by Captains C. M. Wilson and J. M. Mackintosh. The numbers discharged were as follows :—

TABLE IV.

Mustard Gas Cases : Disposal of Admissions to No. 7 Stationary Hospital at Boulogne.

	May–July 1918.	August 1918.	Total.
	%	%	%
Total admissions	254	438	692
Discharged to convalescent depôt.	182 = 71·5	336 = 76·7	518 = 74
Transferred to United Kingdom.	57 = 22·4	70 = 16·0	127 = 18·5
Transferred to other hospitals.	6 = 2·4	10 = 2·3	16 = 2·3
Deaths	8 = 3·2	10 = 2·3	18 = 2·7
Remaining in hospital ..	1 = 0·4	12 = 2·7	13 = 1·5
Total	254 =100	438 =100	692 =100

A glance at this table will show that throughout the whole period the great majority of cases (74 per cent.) were transferred to convalescent depôt, while only a small percentage (18·5 per cent.) were evacuated to England. A comparison between the two periods May–July and August is more striking in the following table, in which an analysis is made of the cases transferred to convalescent depôt, the cases having been grouped according to the number of days under treatment.

TABLE V.

Mustard Gas Cases : Analysis of Numbers Discharged to Convalescent Depôt, Boulogne.

Period in Hospital before Discharge.	Numbers discharged 1918.		
	May–July 1918.	August 1918.	Total.
	%	%	
7 days or less	2 = 1·0	10 = 3·0	12
14 ,, ,, ...	34 = 18·5	128 = 38·0	162
21 ,, ,, ...	48 = 26·0	85 = 25·0	133
28 ,, ,, ...	51 = 27·0	58 = 17·0	109
35 ,, ,, ...	24 = 12·0	31 = 10·0	55
42 ,, ,, ...	6 = 3·0	13 = 4·0	19
49 ,, ,, ...	10 = 9·0	9 = 2·4	19
56 ,, ,, ...	4 = 2·0	1 = 0·3	5
63 ,, ,, ...	2 = 1·0	1 = 0·3	3
70 ,, ,, ...	1 = 0·5	— —	1
Total	182 =100	336 =100	518

From this table it will be seen that more than twice the percentage of cases were sent to convalescent depôt within the first fourteen days in the August period as compared with the previous period. This comparison is all the more remarkable on account of the fact that the occurrence of diphtheria in the wards during August delayed no fewer than forty cases—otherwise convalescent—for a period of twelve days. Thus, but for accident, the number discharged in August within fourteen days would have stood as high as 50 per cent.

The causes that led to evacuation to England varied, as shown in Table VI.

TABLE VI.

Mustard Gas Cases : Evacuated to the United Kingdom from No. 7 Stationary Hospital, Boulogne.

Nature of Lesion.	May–July 1918.	August 1918.	Total.
	%	%	
Keratitis and ulceration of cornea	4 = 7·0	4 = 5·7	8
Severe conjunctivitis and bronchitis	5 = 8·8	10 = 14·3	15
Conjunctivitis with skin lesions elsewhere	2 = 3·5	6 = 8·6	8
Severe and persistent bronchitis	3 = 5·3	2 = 2·8	5
Broncho-pneumonia	14 = 24·5	13 = 18·6	27
Severe laryngitis	3 = 5·3	— —	3
Burns only	5 = 8·8	10 = 14·3	15
Burns and bronchitis	2 = 3·5	4 = 5·7	6
Heart conditions	5 = 8·8	5 = 7·1	10
Miscellaneous	5 = 8·8	3 = 4·3	8
Other diseases	9 = 15·7	13 = 18·6	22
Total	57 =100·0	70 =100·0	127

The number readmitted from convalescent depôts to hospital was no higher, namely, between 2 and 3 per cent., in the Boulogne base, where 74 per cent. were discharged to convalescent depôt, than it was in other bases from which a greater number was evacuated to the United Kingdom.

By following up the times of recovery at convalescent depôts it was proved that at least 75 per cent. of mustard gas casualties admitted to hospitals on the lines of communication may be returned to duty in less than eight weeks. This involves an average stay in hospital of two to three weeks, during the last half of which time the casualties do not require to be in ward beds but may be accommodated in marquees specially for gas cases without nursing orderlies or special care.

The ultimate time of recovery for the most serious cases that were finally transferred from France to the United Kingdom was never fully ascertained. Since the use of mustard gas was confined practically to the last year of the war, clinical study was directed chiefly to the means for speedy recovery of the casualties that could be restored to fitness for duty and towards curtailing unnecessarily long invalidism in these cases. The only report from the United Kingdom dealing with protracted invalidism from mustard gas is that by Meakins and Priestley and their review was written just before the armistice. Chronic invalids from gas poisoning were subsequently transferred from the army to the care of the Ministry of Pensions and the only information available from that source deals generally with poisoning from all forms of gas without special consideration of mustard gas.

Meakins and Priestley analysed the index-cards of 4,575 casualties discharged from various hospitals in the United Kingdom during the period May to August 1918. These would include all the severer cases transferred from France, but more than half of the total number must have been formed of lighter cases, such as would have probably been restored to full efficiency within eight weeks had they been retained in France.

One-quarter of the cases were discharged in the first month, chiefly by transfer to military convalescent hospitals. One-half were discharged in the second month, a large proportion going to command depôts or directly to their reserve battalions. But 787, or 17·2 per cent. of the total, were detained in the hospitals for longer than nine weeks. This latter group would doubtless correspond to the residuum of severest cases transferred from France. No death occurred later than the eighth week after gassing. The main symptoms responsible for delay in hospital beyond the ninth week were :—

Photophobia, probably functional	131
Bronchitis	118
Laryngitis, probably functional	107
Disordered action of the heart	116
Burns	39
Gastritis	35
Conjunctivitis and bronchitis	90
Unknown	75

After four months there were only 76 of these cases remaining in hospital, and these included only 3 cases of skin burns. Ultimately less than 0·5 per cent. were discharged out of this group as permanently unfit. Bronchitis, disordered action of the heart, and neurasthenia were the chief persistent results of mustard gas poisoning, and apparently they persisted in only a very small proportion of the cases.

It should be observed that these figures deal only with cases discharged from hospitals, and do not include patients remaining for treatment in hospital throughout the period under review. But it is unlikely that a large number of chronic gas cases were retained indefinitely in hospitals, and therefore the figures may be accepted as being fairly representative of the actual facts with regard to convalescence in the United Kingdom.

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CHAPTER XVIII.

MEDICAL PROBLEMS IN TANKS.

APART from wounds caused by the direct hit of a shell, the crews of tanks were liable to slight injuries caused by splinters of metal driven from the inner table of the armour plating by the impact of armour-piercing bullets. As a rule such casualties remained at duty, but splinters in the eye proved troublesome, and although a veil made of fine steel wire was devised as a protection it usually proved too cumbersome to be worn with comfort. The explosion of land mines or shells of large calibre near the tank caused a certain number of cases of concussion, and of pain and swelling of the knee and ankle-joints. Burns were common, generally as a result of a direct hit into the petrol tank, though in some cases combustion seems to have been started by the ignition of petrol vapour within the tank by red-hot sparks, a red-hot exhaust pipe, or the blow-back of a 6-pdr. gun. An exanthematous dermatitis resembling impetigo, which affected the exposed surfaces of the skin, was described and was attributed to the irritating effects of petrol fumes or liquid, especially when the lower-grade brands of petrol and oil were used for training purposes. In addition to being responsible for the more serious trouble mentioned below, the exhaust gases of the petrol engines were distinctly irritant, causing a tight feeling in the chest, burning sensation in the nose and throat, and smarting and watering of the eyes. The crews of tanks ran the same risks from warfare gases as did other troops, but it proved somewhat difficult to provide them with a satisfactory respirator. Their vision was so limited in the tank that the ordinary face-piece of the small box respirator formed an intolerable handicap, but the difficulty was finally overcome by fitting the box respirators with special masks to fit over the nose and mouth alone, and supplying separate rubber sponge goggles to protect the eyes when necessary.

One of the most serious disabilities encountered amongst tank crews was dependent on the design and mode of employment of the tank itself, and was in no way determined by enemy action. In a number of instances entire tank crews were put temporarily out of action from this cause at a time when their services were most required. In the early days of tank warfare it was noticed that after prolonged work inside tanks men complained of headache and faintness, and similar symptoms were reported in the case of the crews of tanks constructed at a somewhat later date. It was not, however, till the latest types of tanks came into use that the trouble became really serious, and even the crews of whippet tanks were not wholly exempt.

The symptoms consisted of headache, giddiness, breathlessness, palpitation, vomiting, mental confusion, unconsciousness, collapse, and rise of temperature which was in some cases reported to have reached 102° F. Headache, which was invariably present and in many cases of great severity, came on early and sometimes lasted as long as forty-eight hours. It was usually accompanied by singing in the ears. Giddiness invariably occurred and was accentuated on getting out into fresh air. Breathlessness was frequent and was aggravated by wearing the box respirator and by the irritant fumes within the tank. Palpitation was as common as breathlessness, the pulse being rapid and weak ; as a rule the tachycardia was transitory. Nausea and vomiting were very frequent. Definite mental confusion occurred in at least half the cases. Difficulty in getting drivers to understand and carry out orders promptly was several times reported, the men sitting staring in front of them and merely repeating the orders without putting them into execution, while the depression of the mental power was shown in others by drowsiness and an irresistible desire to rest or sleep. Two cases of defiance of discipline were recorded in which superior officers were attacked. In one instance a man ran about shouting and cursing in an aimless manner, while in another case a man was reported as becoming maniacal. Men sometimes became unconscious whilst in the tank, but more frequently they collapsed on getting out into fresh air. Convulsions were reported on one occasion. One whippet brigade reported that one of the chief symptoms was loss of power in the limbs, " making it impossible to walk or run quickly and taking at one time two men to load a gun." The cases usually presented a pallid or ashen appearance, but sometimes their complexions were red. On an average it took three hours' running in a closed tank for the symptoms to develop ; in a few cases they developed after a quarter of an hour, and in others not until the lapse of six hours. Men who had been affected usually required rest for two to seven days before they were fully fit for duty again. Most of the reports stated that the symptoms were aggravated by the firing of the Hotchkiss and 6-pdr. guns.

The symptoms detailed above were strongly suggestive of carbon monoxide poisoning. Of this there was certainly no small risk in the later forms of tanks. The exhaust pipe from the engine ran for some little distance within the tank before perforating the plating to reach the outside. Any leakage of one of the joints in the exhaust system within the tank would allow exhaust gases containing a high proportion of carbon monoxide to escape, and starting of the joints might easily be caused by overheating of the exhaust pipe and by the vibration. The exhaust pipe itself was surrounded by a duct, up which air could be sucked from the interior of the tank by a small centrifugal fan to be expelled to the exterior, the object being to cool the exhaust pipe. This fan was, however, extremely liable to fail from overheating of its bearings, since the exhaust pipe was usually red-hot when the engine was running hard. The ventilation of these tanks was by no means adequate. The radiator of the engine was situated at the after end of the tank, and air for cooling it was sucked in from outside the tank by a large centrifugal fan and driven through the radiator to escape to the open air on the opposite side. The ventilating system of the radiator was entirely cut off from the interior of the tank save for one small opening which led into the fan duct. This opening could be closed by a shutter, and it appeared to be frequently left closed in practice, while in any case it was in a position where it was liable to be obstructed accidentally. Openings in the walls of the tank, gun-ports and the like, were too small to permit of effective natural ventilation. The risk of carbon monoxide poisoning from leakage of exhaust gases would, of course, be greatly accentuated by the blow-back from the guns.

There was, however, another factor to be considered besides carbon monoxide, namely, the high temperature which prevailed in the tank when the engine was kept running for any length of time. The inadequate ventilation and the presence of a full crew on board gave opportunity for the accumulation of an undue amount of moisture in the air, so that a serious rise of the wet bulb temperature might be anticipated in addition to the rise of the ordinary dry bulb temperature. The wet bulb temperature, since it affords an indication of the cooling effect which may be produced by the evaporation of water, is of vital importance when the dry bulb temperature of the air in which a man is situated becomes high enough to hinder materially loss of heat from the body by radiation, convection, and conduction. Preservation of a normal body temperature in these circumstances comes to depend more and more upon the cooling effect produced by the evaporation of sweat from the surface of the skin, and when the dry bulb temperature is at or above body temperature a sufficiently rapid evaporation of sweat becomes the all-important factor. Though a man may stand with impunity very high dry bulb temperatures, the limit of toleration is reached when the wet bulb temperature rises to 89° F., for even if he is stripped of clothing and sitting still the sweat cannot under these conditions evaporate sufficiently quickly to keep the body cool, and the body temperature consequently begins to rise. A material rise of body temperature thus caused in a normal man is liable, if maintained for any length of time, to give rise to marked malaise and exhaustion. Should the heat production of the body be increased by the performance of muscular work, the wet bulb temperature that can be tolerated without causing a rise of body temperature will be considerably below 89° F.

That the risks associated with both accumulation of carbon monoxide and high temperature were real was clearly shown by some experiments conducted in September 1918 at the headquarters of the Tank Corps in France. In one instance a late type of tank was closed up as it would be in action, and run hard along a track for an hour and a half. It was then stopped for a few minutes with the engine running light at slow speed, after which it was again run hard along the track for twenty minutes while observations were being made. The temperature in the centre of the tank at the beginning of this last period was 118° F. dry bulb and 85° F. wet bulb, and at the end 120° F. dry bulb and 86·5° F. wet bulb. A distinct though small amount of carbon monoxide was found in samples of air taken from six different points in the tank, the concentration being greatest in the vicinity of the exhaust side of the engine and least in the front of the tank where the driver's seat was situated. One observer who had entered the tank for the twenty minutes' observational period, and had sat still throughout, showed a normal body temperature at the end, but the second observer showed a mouth temperature of 100·5° F. immediately after leaving the tank, while half an hour later his temperature had fallen to 99° F. The driver, who had been in the tank all the time, had a mouth temperature of 100·4° F. a few minutes after leaving it, but his seat appeared to be cooler and better ventilated than the remainder of the tank. Other experiments gave confirmatory results.

No direct examination of the blood for carbon monoxide was ever made in the case of a disabled tank crew, but rise of body temperature was often noticed, as pointed out above, so that some uncertainty must remain as to the relative importance of the two dangers. The symptoms reported in the more severe cases were certainly in many instances typical of carbon monoxide poisoning. At the same time it was often noticed that men who were unaccustomed to tanks, such as infantry, were liable to show symptoms somewhat rapidly of malaise, collapse, and vomiting. In such cases high temperature may have played the predominant part. The more crowded the tank was with men the faster would the wet bulb temperature rise, and, in addition to this, other experience has shown that it is by no means uncommon to find that men who are unaccustomed to high temperatures are seized by faintness when exposed to an unusually hot environment, even though their body temperature at the time may not yet have risen significantly. It is possible that the irregular motion and vibration of the tank may have helped to upset men who were unaccustomed to it.

There was another method by which carbon monoxide might gain entry into a tank, and this was undoubtedly responsible on several occasions for serious poisoning of the crews. The exhaust pipe, after perforating the plating of the tank, was carried to the after-end where it opened to the air. With a following wind there was no small risk of the exhaust gases being swept forward as they left the pipe and finding entry into the interior of the tank through some aperture. Again, if there was little wind, or only a light following one, and tanks were following close behind one another in line during an approach march, the exhaust from one tank was liable to gain entry into the tank following it. A good instance of the latter danger is afforded by the following account taken from a report of the medical officer attached to the 13th Tank Battalion. The episode occurred during operations on 24th September, 1918.

> "There was a considerable quantity of enemy gas encountered going up to starting point, at starting point, and during action. However, in the case of one tank the symptoms developed in a marked degree before arriving in the gas zone. In this tank the first driver became totally unconscious and was found lying forward gripping his controls with a convulsive grip that was difficult to loosen. This man had to be evacuated to a dressing station. The second driver, having taken over, also became unconscious after some time. The tank commander then took over, and himself became unconscious and had to be taken out of the tank. This tank was unable to get into action owing to the condition of the crew. Both officer and men are under the impression that it was the fumes from the tank in front, which they were following closely, that materially helped in causing the trouble. Another tank, in which every member of the crew was affected, complained of some of the symptoms before arrival in the gas zone. The first driver stated he was affected in a similar manner during the approach march of the previous night. I am convinced that the symptoms noticed in this action and previous actions are due to petrol combustion gases, as they closely correspond with symptoms of cases I have seen of men gassed by fumes in motor lorries."

The clear solution of the difficulties, no matter whether they arose from the presence of carbon monoxide or from high temperature, was to improve the ventilation in the tanks that were found to be at fault, and steps taken in this direction were yielding promising results shortly before the armistice. The danger arising from exhaust gases from one tank finding entry into a tank following it could be overcome by increasing the distance between the tanks if proceeding in line one behind another, or by adopting formation in echelon. The reason why relatively little trouble was met with in the earlier tanks was to be found in their better ventilation. In them the whole of the air which passed through the radiator was sucked by a centrifugal fan from the interior of the tank and escaped to the open air, so that there was a constant entry of fresh air into the tank through the gun-ports and other apertures. The whippet tanks, too, had better ventilation than the later large types.

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CHAPTER XIX.

GAS POISONING IN MINE WARFARE.

THE use of mining in warfare dates back to remote antiquity. The question of ventilation was always troublesome, and one frequently reads of the difficulty experienced in getting lights to burn at the working face where the galleries were long, and of men being overcome by the deficiency of oxygen and increase of CO_2. To show how little novelty there is in warfare, an ancient historian describes the use of asphyxiating gas in mining in 189 B.C. at the siege of Ambracia, where the Aetolians filled jars with feathers which were set on fire, the smoke being blown by bellows into the faces of the Romans.

With the introduction of gunpowder in the fourteenth century the possibilities of offensive mining were enormously increased, and it played an important part in all phases of fortress warfare. In the sixteenth and seventeenth centuries gas poisoning was of frequent occurrence, many casualties being caused, and a train of symptoms following exposure to the fumes from gunpowder became recognized. In France these were grouped under the term "*mal des mines*," and the peculiar mental condition met with in men who regained consciousness was graphically described as "*l'enivrement par la poudre*." A German commission towards the end of the seventeenth century enquired into gas poisoning in war mines, but made no important contribution to the subject unless to advise the use of pigeons as indicators of danger. It seems to be quite unknown that pigeons and rats were used as gas indicators centuries ago.

In recent warfare the Japanese used mines to destroy the Keikwansan Fort in Port Arthur. The scheme was ambitious, but it resulted in serious disaster to the attacking troops, fifty of whom were killed by the explosion which blew back into the sap-head, probably as the result of defective tamping. This delayed the assault of the infantry. Five hundred of the garrison were killed outright by the force of the explosion or by the fumes.

In the war of 1914–18 in the early days of mine warfare, which commenced in January 1915, all mining operations were of a defensive character, important trenches, salients or sectors of the line being guarded by mine systems. At first operations were simple, a single gallery being driven to the point desired, while the charge was always small. As mining operations developed, offensive mining, which calls for much more extensive workings and greater charges, was found to be the best defence. By the autumn of 1915 mining had made huge strides. Owing to the great increase in size of the explosive charges used in mines and camouflets, following upon the increased depth of mines, the more extensive mine systems and the consequent increased personnel employed, the casualties from gas poisoning assumed serious proportions. Before a system of rescue work and of protection against gas in mining could be organized, one company in a month had suffered twelve killed by gas, twenty-eight sent to hospital, and sixty minor cases retained with the unit. In another company in five weeks sixteen were killed by gas, forty-eight were sent to hospital, and eighty-six minor cases were treated at the shaft-head and returned to the company billets. Other companies in the chalk area suffered in similar fashion. As most of these men were skilled miners, whose places it was almost impossible to fill at the time, the wastage affected in a very marked way the efficiency of companies.

From 1915 to June 1917, many thousands of men were daily employed underground. It may convey some idea of the intensity of the mine warfare waged and the opportunity for gas poisoning and other casualties occurring, when it is stated that in 1916 the enemy fired 696 mines and camouflets, and the British 750. The most active month of this year was June, when the British blew 101 mines and the Germans 126. Some of the galleries at the Somme were 120 ft. below ground level. At the battle of Messines, in which mining contributed greatly to the success of operations, nineteen huge mines, some of which were charged with over 90,000 lb. of ammonal, were exploded. To give some idea of the work involved, it should be stated that about 25,000 ft. of gallery were driven, and that the total charge of explosives in these mines was over one million pounds.

Explosives used in Mining.

Before describing the various ways in which gas poisoning in mines may arise, it is necessary to give some information about the explosives used in mining, as the question of gas poisoning is much affected by changes in the explosive. When an explosive is ignited it burns at the rate of a few yards per second, ignition proceeding from point to point by the heat generated. The products of combustion from burning are quite different from those formed by explosion or detonation.

When the rate of combustion is much more rapid, as is seen in gunpowder and such explosives as cordite, which are used as propellents, the term explosion is used, although this term is also loosely applied to detonation. In explosion, combustion is confined to the surface, passing from layer to layer of the explosive, in this way differing from detonation.

In another class of explosives the chemical equilibrium of the substance is so unstable that it is easily disturbed by a blow. The change in the mass of explosive once initiated is propagated as an explosive wave with immense velocity. This almost instantaneous disruption of the explosive, which proceeds through the mass, not from layer to layer, is called detonation. If, owing to any circumstance—deterioration of explosive, insufficient detonators, or imperfect tamping—the wave of detonation dies out and a slower form of combustion results, incomplete or partial detonation is said to have taken place, in which case the products of combustion are considerably altered, much more CO and also nitrous fumes being formed.

Explosives used in military mining must fulfil the following conditions : (1) Reliability in action, (2) safety in handling, etc., and (3) powerful lifting and shattering effects, these being obtained by rapidity of detonation and the production of much heat and gas. The production of much CO by an explosive was a serious drawback to its use in certain circumstances, especially in blowing camouflets. In the intensive crater warfare, which was waged continuously for so many months, it was frequently necessary for the infantry to occupy the craters very quickly after they were formed, and in many cases it was necessary for work to be resumed in the blown galleries as early as possible.

For several centuries gunpowder was the only explosive used in military mining. In the war of 1914–18 it was very little used in mining operations. In the early days of mining in 1915 wet gun-cotton, which was the only explosive used in the army for demolition work, was employed, but was quickly abandoned as it gave most unsatisfactory results underground. It produces more CO than any other explosive—over 40 per cent. if there is complete detonation, and as much as 54 per cent. if detonation has been incomplete. Experience showed that it was very difficult to clear the mine of gas after this explosive had been used, as the disturbed ground and that in the vicinity appeared to become quite saturated with gas, and there was frequently trouble when the tamping was being removed owing to gas welling out.

Nearly every explosive used in mining both by the allies and by the enemy belonged to the ammonium nitrate group of high explosives. They were used on an enormous scale. Generally speaking, they contain an excess of oxygen and theoretically should give rise to little or no CO. But they appear to vary considerably in this respect and in the conditions under which they were generally employed they produced considerable quantities of this gas. All the explosives belonging to this group are hygroscopic and in the presence of moisture large quantities of CO are generated. Ammonal was the explosive which was most used by the British during the period of greatest mining activity. The fact of its being so greatly hygroscopic was a serious drawback in the wet and shallow mines which were frequently driven in 1915, but in the deeper mines which were the rule later on in mine warfare this drawback was not so important as there was much less water. Not only so, but the tunneller had learnt the necessity of " keeping his powder dry." Trinitrotoluene (T.N.T.) a constituent of ammonal, is itself very deficient in oxygen, so that even when fully detonated large quantities of CO are formed. The addition of ammonium nitrate considerably lessens the amount produced.

Afterwards, owing to the difficulty in getting aluminium, amatol, blastine and sabulite were used. The last gives rise to much more CO than does ammonal. Blastine is less hygroscopic than ammonal, and was therefore of value in mining in wet ground. It gave rise to more CO than ammonal and had another characteristic—the fumes produced, which contained hydrochloric acid as well as CO, were exceedingly pungent and irritating. This, however, may have been a safeguard, it being very unlikely that men would penetrate into an atmosphere of this character.

Most of the mining explosives used by the enemy, *e.g.*, Donarite, Glückauf, and Westfalite, belong to the ammonium nitrate group and resemble ammonal and amatol. They all produce CO when detonated. These explosives were latterly largely replaced by perdite, which is very similar to cheddite, a favourite mine explosive in France.

Gelignite cartridges were used for blasting at the face in hard chalk in mining and in the construction of subways and dugouts. Occasionally minor cases of gas poisoning were caused in places not in the air current, more particularly in badly ventilated galleries, owing to the men returning too quickly to the face after shots were fired.

The enemy employed liquid oxygen very extensively as an explosive for demolition and for blasting operations in the making of dugouts and tunnels. This explosive was first used on a big scale in the making of the Simplon Tunnel, where operations had been seriously affected and delayed by the contamination of the atmosphere from blasting by nitroglycerine explosives. Liquid oxygen is safe to handle, powerful in action, and it produces no CO. In the case of a misfire another advantage is that the charge, owing to the evaporation of the liquid oxygen, becomes automatically safe in about twenty minutes.

Cause of Gas Poisoning in Mines.

By far the greatest number of gas poisoning cases in mining was caused by carbon monoxide. As this gas is not naturally present in the soil, it could only result from the explosives used. Under certain conditions large quantities of CO may be produced from all explosives. The amount depends not only upon the type of explosive used, but upon the quality. Deterioration of the charge or of the detonators, from whatever cause, may lead to incomplete or imperfect detonation of the charge with the consequent production of large quantities of CO. Bad quality of explosive or of detonators, insufficient or weak detonators, may also have a similar effect. Some of these conditions may be produced when a charge has been poorly laid and tamped for some time in damp workings.

When a mine was exploded, the galleries and shafts of the mine were filled with gas. There was much less trouble from gas after the enemy had fired a mine (crater formed), than after a camouflet, where the surface of the ground is not broken. It was found that when the galleries were driven through Ypresian clay, as in mining in Flanders, the mines quickly cleared of gas, and the ground did not become impregnated with CO to any such degree as happened when the galleries were driven through chalk or other pervious strata. In certain cases where sufficient time had been allowed for the fumes to be dissipated and the air of the gallery had been proved by the use of canaries to be free, it was found that, when the men commenced to remove the tamping, they were frequently affected by the gas which was liberated. Many cases of gas poisoning were caused, especially in the chalk areas, when the

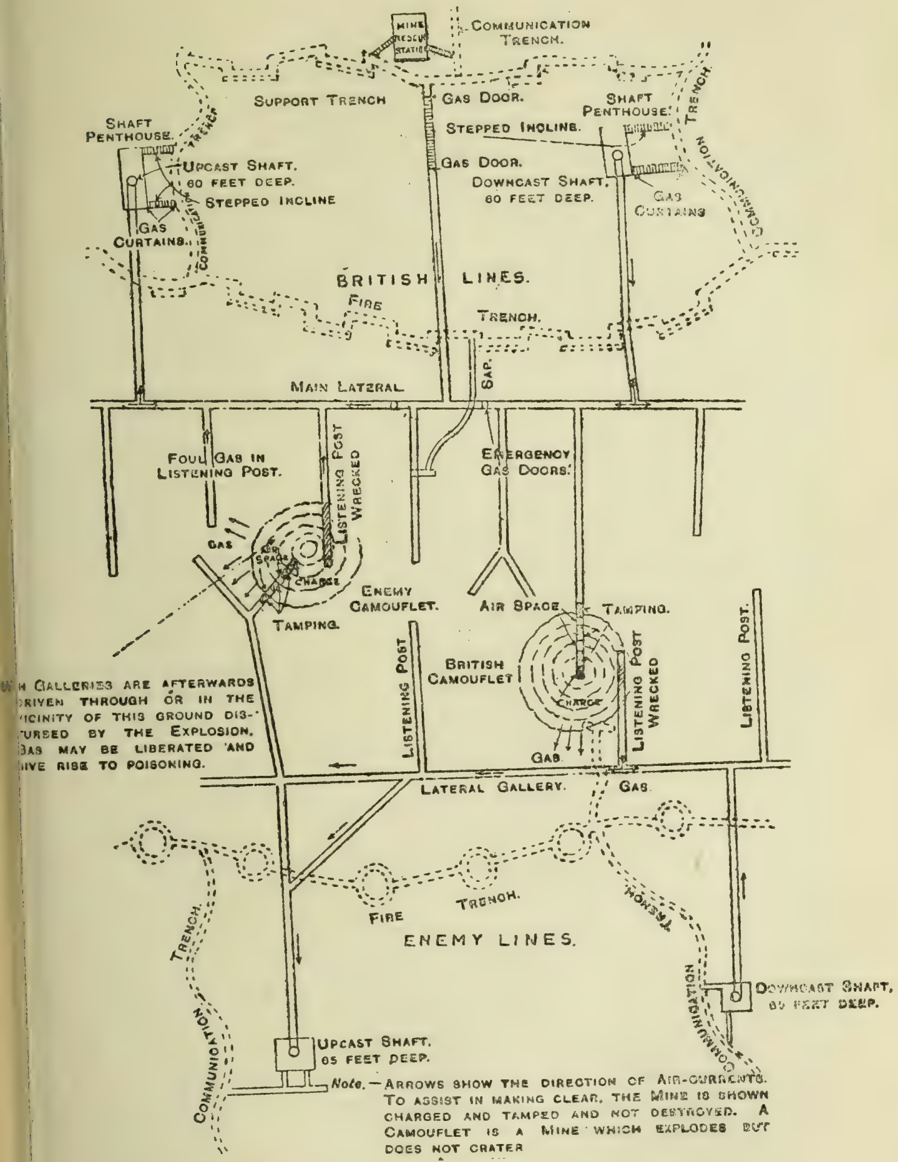

Fig. 1.—Diagram of trenches and mine galleries, showing effect of camouflet and mine gas on galleries and ventilation.

galleries were driven through ground disturbed by previous blows or in its vicinity. In certain parts of the disturbed area large collections of gas were tapped ; these were known as " pockets of gas." The gas sometimes came through in distinct puffs with a hissing or whistling sound, showing that it was escaping under pressure. In the early days of mining this gave rise to one of the many rumours which were spread round tunnelling companies that the enemy were employing a new gas and forcing it through into the British galleries. The insidious nature of the poisoning and the serious number of casualties naturally tended to support these rumours. The same rumours were common in the enemy lines, where it was reported that the Allies were employing cyanogen.

Fumes from explosives frequently lose their distinctive odour after percolating through the soil, and are consequently much more insidious. It sometimes happened that, after a small hostile camouflet, the miners in the neighbouring galleries were so little disturbed by the explosion that they went on working. In the course of time gas penetrated to these galleries and poisoned the men there. To prevent such accidents the order was issued, " When a blow occurs, even though this appears to be a long way off, all men working below must come up at once."

Sudden inrushes of gas into galleries which were free of gas were sometimes encountered owing to (*a*) sudden settling of the ground by whatever cause (rain, another blow, etc.) forcing the contained gas into the gallery ; (*b*) changes in atmospheric pressure ; and (*c*) changes in the water-level.

On certain occasions, after the explosion of an enemy mine, gas has poured from the shaft and poisoned men who were in the trenches in the immediate vicinity. In such cases serious gassing is more likely to occur where the trenches are very narrow, and also where the weather conditions (absence of wind, heavy dull atmosphere) are unfavourable for the rapid dispersion of the fumes in the open. The infantry were warned against taking shelter in the mine-shafts, dugouts or chambers from the shell fire which accompanied an enemy mine explosion, as these places became regular death-traps.

In driving galleries and making dugouts in hard chalk it was frequently found necessary to use gelignite charges for blasting, and occasionally cases of poisoning arose from men returning to the face too soon after the shots had been fired.

Vertical shafts formed by exploding bore-holes and lined with cylinders of corrugated iron were used in the rear zones in the construction of machine gun dugouts. They formed a quick method of providing central shafts for large dugouts. One case of CO poisoning occurred owing to a man descending the shaft in order to inspect the result of the explosion before the fumes had cleared. The preventive measures to be adopted here and in blasting at the face are obvious.

Carbon Monoxide Poisoning in Craters.—One of the most important features of the stationary trench warfare of 1915, 1916 and part of 1917, was the continuous fighting for craters. It frequently happened that only a very few minutes elapsed between the moment when a mine was exploded and the occupation of the crater by the infantry, the establishment of bombing posts, etc., and the taking of other means to consolidate the position. Seeing that charges of many tons of explosive were frequently used, it would have been thought that there was considerable opportunity of gas poisoning. But the loose porous condition of the earth in the crater, the mounds (lips of the crater), and ground in the immediate vicinity, allowed gas to escape readily, and, as in ordinary circumstances this would be quickly dispersed, gas poisoning cases among the infantry occupying the crater did not often occur. In several demonstration mines which were fired when a slight breeze was blowing and which detonated well, canaries carried into the crater immediately after the ground had settled showed no signs of distress. It was only when large quantities of gas were formed, as with an incompletely detonated mine, and when atmospheric conditions were favourable (absence of wind or a dull heavy atmosphere), that gas collected and poisoned the men who had rushed the crater. When these conditions prevailed it was customary to take all the necessary precautions.

At the battle of Messines the following precautions were taken : All trenches, shallow dugouts and subways within a radius of 400 yards of the mines were vacated before firing. In order to avoid all danger from gas poisoning the assaulting troops were ordered to avoid the bottoms of craters and to confine any work of consolidation to the top, and at least 10 ft. from the lip. A number of the infantry, however, who for various reasons, such as wounds, had been forced to halt in the immediate vicinity of the craters, were more or less seriously affected by the gas. The weather conditions were in favour of slow dispersal of the gas.

In the French army a number of serious cases of gas poisoning occurred, men while consolidating the craters of mines which had just been blown having been known to fall and die in a few minutes. In some of these cases rescuers who were not wearing apparatus were also overcome. According to captured German documents, cases of CO poisoning in mine craters only occurred in very exceptional circumstances, such as when craters were occupied immediately in dull weather, more especially when the mine had imperfectly detonated.

One very interesting case of poisoning occurred in 1916, while a crater in the Hulluch sector of the line was being consolidated. The infantry had been warned by the tunnellers that the enemy might spring a mine, and were in readiness. Immediately the mine went off they rushed forward and occupied the front lip of the crater. Two bombing posts were dug on the rear slopes of the two mounds of chalk, and two saps were run out from the front line to connect up these posts. Whilst digging the saps one man was overcome after working for about ten minutes, and another after working for twenty minutes. In this case the sap was being driven through soil impregnated with gas, which could not readily escape owing to the surface soil not being much disturbed, so that the gas welled out ; in such circumstances, if atmospheric conditions are favourable, as was the case here, gas poisoning may result. Where a thick bed of brown clay overlies chalk, this danger has to be guarded against owing to the clay tending to prevent the diffusion of the gas from the surface of the ground.

Occasionally the gas exuding from the broken ground in the crater became ignited, forming walls or pillars of flame from a few feet to 12 ft. high which burned for hours. This provides an excellent demonstration of the amount of gas formed by the detonation of a large mine. When gases burn the products of combustion are innocuous. The following is a very good example of flames appearing in a crater. A mine was blown by the enemy. The shape of the crater, gas effects, and history of the blow suggested a poorly tamped charge, placed in a gallery without chambering, which had detonated incompletely. On the left-hand slope of the crater a series of blue flames was seen burning in an almost continuous row. The flames along this line burned regularly and were apparently produced by the burning of gas issuing from a crack in the chalk. Elsewhere there was no continuous flame, but occasionally a blue flame danced over the crater at other points. A canary taken to the bottom of the crater showed no signs of being affected by gas. For three hours the flames continued to dance and break with a popping sound. It was a particularly calm night and within the crater there was not the slightest wind to clear away the rising gas. Mine rescue men with apparatus stood by throughout the night in case the infantry in the crater should be affected. Bombers were lying along the front lip till dawn, but no ill-effects from the gas were experienced. Although the infantry occupying the crater run less danger from gas poisoning when the gas is burning, care must still be exercised.

Explosion of Gas in Mines.—Gases from the detonation of a high explosive include carbon monoxide, hydrogen, and methane, all of which are combustible and, when present in the proper proportion, explosive. Methane is never formed at the time of detonation but results from the action of hydrogen on the oxides of carbon as the gas cools down, which it quickly does in the galleries. The greater the amount of hydrogen formed, the greater will be the proportion of methane. It was found that, when any of the ammonium nitrate group of explosives was detonated in the open, *e.g.*, a mobile charge in a shaft or gallery or in an imperfectly tamped mine, more CO, hydrogen, and methane were formed than when the explosive was detonated in a well-tamped mine.

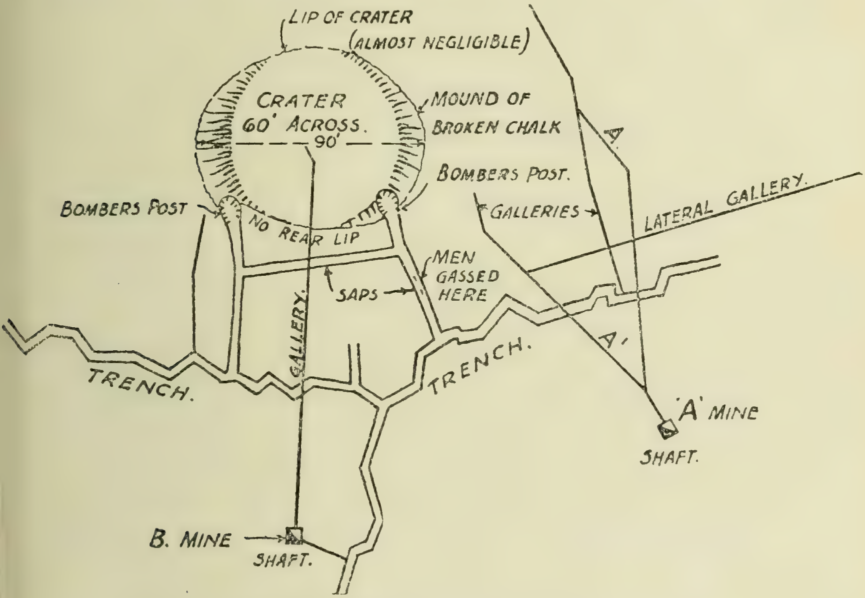

Fig. 2.—Diagram showing crater, mine galleries and saps.

In some of the secondary explosions which were investigated all these gases were present, but in others there was so little CO that canaries exposed to the atmosphere were unaffected.

The tendency of the gases to explode will depend on certain factors : (1) The amount of gas present ; (2) the initial velocity of the gases issuing from the camouflet (the greater the velocity and the greater the density, the greater will be the liability to explode) ; (3) the size of the galleries (the smaller the galleries, the greater will be the pressure and concentration of gas).

When explosive gases are ignited they do not explode at the point of ignition, but at a certain distance away. What happens is that the flame passes along at a uniform rate to a certain point where, if there is sufficient gas to feed it, vibrations are set up which become more and more rapid until explosion occurs. When the gas is present in insufficient quantity or in non-explosive percentage the flame becomes spent. The result is that evidences of explosive damage done to a gallery are never found at the point of ignition, but some distance away, and the men in the vicinity of where the gas has been fired suffer from burns and not from injuries caused by the force of the explosion. One grave danger from explosions of gas is the rapid flooding of the mine system by gas from the camouflet owing to the combustion and explosion of the gas in the galleries causing a partial vacuum.

Attention was first directed to gas explosions by a serious explosion which occurred in January 1916, when a tunnelling company suffered considerable casualties. As this conveys a very good example of one of the great dangers of military mining, a short description of what occurred may be of interest. The danger of carrying a naked light into a mine, in which gas in small quantity was known to be present, was not appreciated. In such cases it should be remembered that gas may be present in explosive proportion, and that the quantity may be suddenly increased owing to various causes, such as changes of atmospheric pressure, and settling of ground saturated with gas. The following is an example of this :—

> At 2.15 p.m. the enemy exploded a camouflet. From all accounts the explosion was not intense and the damage done to our galleries was small. The probabilities are that the mine had been charged and tamped for some time, that the charge had deteriorated, and that part of it had been incompletely detonated, with the result that large volumes of carbon monoxide, hydrogen, and methane were formed. At the time of the explosion four officers and a considerable number of men were in our galleries. The exact positions of the officers and most of the men at the time of explosion were known (see Fig. 3). There was an order that as soon as an explosion occurred everyone must leave the mine, and an attempt was made to carry this out. At first gas from the camouflet came along the galleries, but not in sufficient strength to overcome those in the mine, although they began to feel the effects of it. Certainly they were not exposed to gas of sufficient strength to give rise to an explosion, for they would have been quickly overcome by it, and it is known from the movements of an officer that this was not so. Suddenly

there was a rush of gas from the camouflet. This passed down a branch gallery to the transversal, where it was ignited by the candles of two men whose caps were found here ; it exploded farther along the transversal, killing an officer. As before mentioned, in certain proportions of explosive gases the explosive effect at the point of ignition is practically *nil*, and anyone at that place would suffer from burns and not from the shock and injuries

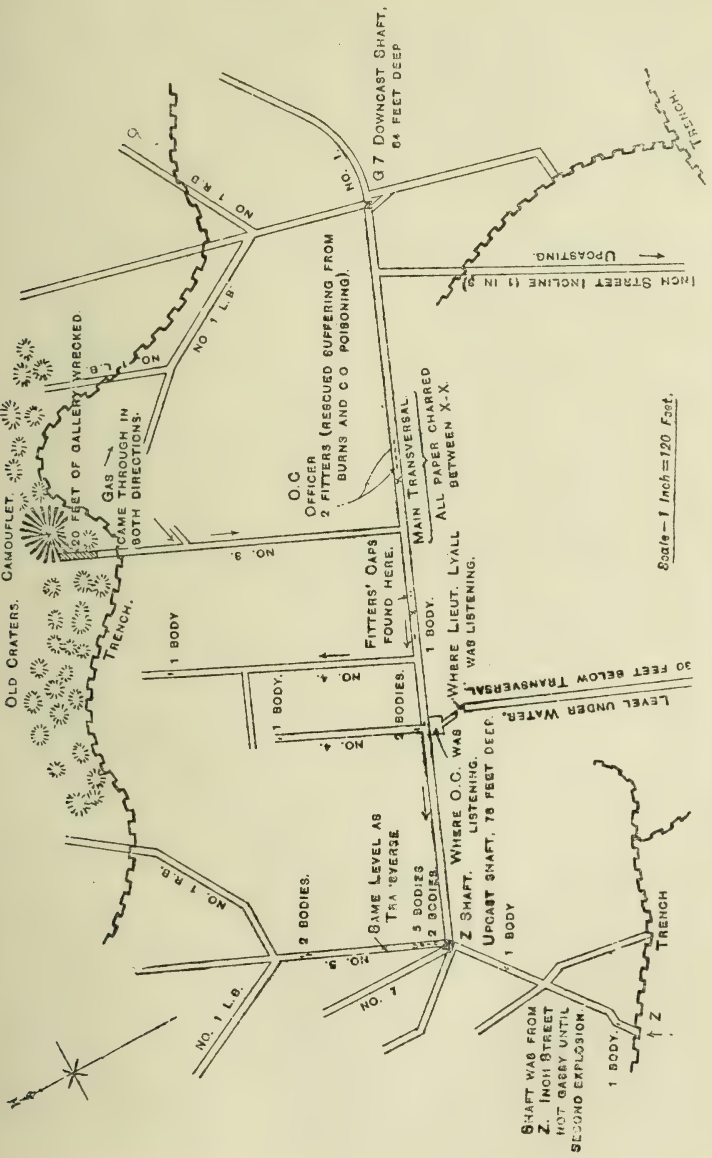
G 7 Downcast Shaft, 84 feet deep
Trench
No. 1
No. 1 R.B.
No. 1 L.B.
No. 1 L.B.
Upcasting
Inch Street Incline (1 in 9)
German Camouflet.
Old Craters.
120 feet of gallery wrecked.
Gas came through in both directions.
Trench.
No. 3.
O.C.
Officer
2 Fitters (rescued suffering from burns and C O poisoning).
Main Transversal.
All paper charred between X-X.
Fitters' Caps found here.
1 body
1 body.
Where Lieut. Lyall was listening.
No. 4.
1 body.
No. 4.
2 bodies.
30 feet below Transversal
Level under water.
Where O.C. was listening.
Upcast shaft, 78 feet deep.
Scale—1 Inch=120 Feet.
No. 1 R.B.
2 bodies.
No. 5.
Same level as Traverse
3 bodies
2 bodies
Z Shaft.
1 body
No. 1
No. 1 L.B.
Trench
Z
1 body.
Shaft was from Z. Inch Street not gassy until second explosion.

Fig. 3.—Plan illustrating an explosion of gas from a German camouflet.

from the explosive wave. And this is what was found; the men who ignited the gas, and who were afterwards rescued, suffered from burns and CO poisoning, while at the point of explosion an officer was killed by the violence of the explosion. As a result of the explosion of the gas in the transversal and its ignition along the branch gallery a partial vacuum was caused which produced another influx of gas into the galleries. This passed along the upcast (the direction of the circulation of air as frequently happened after an explosion having been altered, the downcast becoming the upcast), and led to the death of the men who were working in this part of the mine workings. Two officers were killed, one by the violence of the explosion, the other by burns and CO poisoning, and sixteen lost their lives from CO poisoning. Splendid work was done by the rescue men of the company, who saved a number of lives. The rescue operations on the surface were conducted under heavy shell fire. The following order regarding lights was immediately issued:—

"After a blow, no naked lights are to be used in the mine till it is clear of gas. Electric lights only are to be used, as the gas in the mine may be present in explosive amount. When men are in a mine when a blow occurs and their lights are extinguished, they should make their way out without re-lighting them; and where the force of the blow has not been sufficient to put out the candles they must be immediately extinguished."

Even when explosives such as gelignite, blastine, cheddite, etc., are used in blasting, sufficient gas may be given off to cause an explosion if ignited. One example of this will be sufficient to show how such cases arise.

In making a deep dugout in very hard chalk, cheddite cartridges were used for blasting. Four shots were fired, of which two failed to detonate, one detonated imperfectly, and one completely. After twenty minutes had elapsed the men returned to the face to examine the effects, when an explosion occurred. The leading man, whose candle had ignited the gas, was burned about the face and hands and two other men were slightly gassed. It was found that one of the cartridges had burned instead of detonating. The explosive used had been stored for a long time and had deteriorated.

The use of time fuses with shells and trench mortar bombs leads to conditions under which large volumes of gas under pressure may occur. This was experienced while an entrance to a dugout in clay was being driven. When a depth of about 10 ft. was reached a cavity was suddenly broken into, and a rush of inflammable gas into the working took place. The gas was immediately ignited by the candles in use, causing an explosion by which four men were severely burned. Investigation showed that this cavity had been formed by the camouflet produced by a large shell with delay action fuse. The detonation of the shell had been incomplete, but was sufficient to seal the hole formed by the shell and so imprison the gases. Tunnelling companies were at once advised of this danger encountered in shelled areas and of the precautions which should be taken.

Another of these interesting and unusual explosions occurred during trench mortar bombardment of an area where the ground consisted of brown clay about 6 ft. in thickness with soft chalk below. An infantry subway had been made with about

12 ft. of cover over the gallery to an advanced machine gun post. During the bombardment a minenwerfer bomb buried itself, penetrating to a depth of 8 ft., the explosion producing a camouflet chamber of a roughly spherical shape and about 6 ft. in diameter. The timber of the gallery was cracked and had to be replaced. While this was being carried out a sapper broke into the cavity, and a jet of gas shot out into the gallery, igniting at a candle stuck on the timber supports. The sapper was severely burned about the face and chest. It is surprising that with such a small amount of cover so large a chamber should have been formed, and the gas retained under pressure for more than six hours.

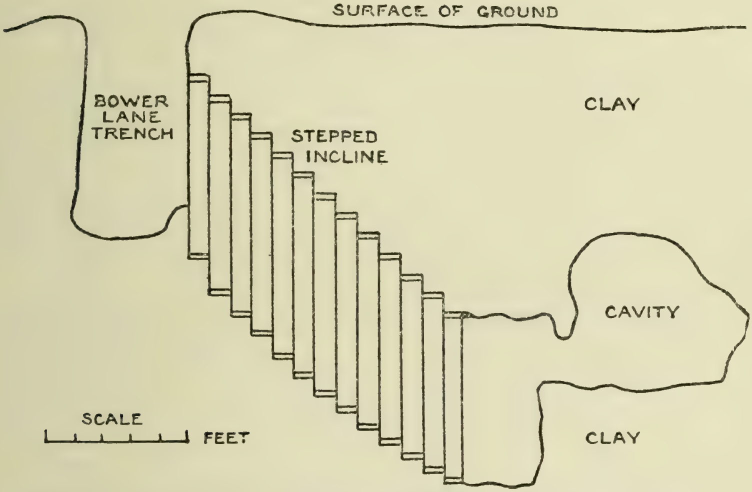

Fig. 4.—Gas explosion: Sketch showing particulars of explosion of gas from cavity formed by delay action shell.

Gas Poisoning due to Faulty Engines. A few compressor plants were installed in the hard chalk areas for ventilation and for drilling. When first used gas poisoning occasionally occurred when the intake of air to the compressor was situated too near the exhaust; and when the exhaust opened into a covered way from the surface through which the men had to pass. Orders were given that the intake must always be from outside the compressor dugout and away from latrines, drains, or stagnant pools of water, and that the exhaust should always open outside and far from the intake. Where the men depended on the compressor plant for ventilation, the necessity for these orders is obvious.

Gas poisoning was also caused by the use of unsuitable lubricants (generally castor oil or lubricant oil used for motor lorries) in the cylinder of the compressor engine, with the result that air charged with CO was delivered to the galleries. The oil sometimes collects in the pipe from the compressor to the receiver, as well as in the latter, and if excessive heating of the cylinder is allowed to take place the oil may be set on fire. From experimental work with oils of low flash-point it has been shown that when distillation was carried out under pressure and at a high temperature CO was produced. To prevent such accidents the following order was issued: " Only pure mineral oil of proper characteristics and high flash-point as supplied for this purpose should be used for cylinder lubrication. Care should be taken to prevent over-lubrication, and also that the water-cooling system is efficient."

In one case where a compressor was in use cessation of ventilation for a short time, in order to enable listening to be carried on without interruption in a gallery where there was a small percentage of gas, led to casualties owing to the gas collecting in dangerous quantity. In another case after an enemy blow the ventilator was run at full speed, and in a short time the atmosphere was sufficiently good to permit the men to resume work. Suddenly, owing to a breakown of the ventilator from belt trouble, ventilation ceased; this led to serious gas poisoning of those in the mine. Companies were advised that, in such cases where the men were relying on the ventilator for air so soon after a blow, there must always be some arrangement to warn those in the mine should anything go wrong with the plant.

Small power petrol engines were very largely used along the whole front for power purposes and were usually installed in dugouts. Cases of poisoning by the exhaust were not infrequent, owing to the dangerous character of the gas not being appreciated especially at the time when these engines were first used. The power-stations for the lighting plants were placed in large dugouts constructed off subways, the engine exhaust being taken to the surface through a pipe in a 6-in. calyx bore-hole. The lighting sets were from 4 to 20 h.p. at 220 or 440 volts., and were of various types. Poisoning occurred where care was not taken to ensure that the exhaust discharged into the open air, and that the pipe was carried away from all covered passages connecting the engine with other dugouts or subways through which men had to pass. Poisoning also occurred where the exhaust pipe had become blocked or badly damaged by shell fire. In these circumstances men in dugouts have been seriously overcome. Special instructions were early issued regarding these dangers. The following examples will give an idea of how accidents arose, and point to the necessity of paying particular attention to the ventilation of dugouts used as engine rooms. This included the duplication of all bore-holes as exhaust shafts and the provision of two entrances to an engine-house.

A small engine (3 h.p.) for operating a pumping station was installed in a dugout. No attempt was made to convey the exhaust directly into the open air nor to ensure, by proper ventilation of the engine dugout, a sufficiently good supply of inlet air to the engine. Very soon after being started the engine began to run badly. As the inlet air deteriorated, becoming poorer in oxygen, more and more difficulty was experienced, the engine misfiring frequently. Two men who were in an adjacent dugout communicating with the engine dugout were poisoned by the exhaust and were dragged out in an unconscious condition. The engine continued to run badly. The officer in charge, in order to find out what effect the pumping had on the water in the shaft, approached with a naked light, with the result that the petrol vapour was fired and he was badly burned about the face and hands.

During a stand-to at Tor Top, a number of men were more or less seriously affected by fumes from a petrol engine. The plant was immediately closed down and the infantry evacuated from the extensive dugout system. On examination it was found that a shell had partially stopped up the bore-hole exhaust pipe, so that the exhaust gas could not escape. A faulty part of the engine exhaust was awaiting repairs.

The first incident occurred soon after petrol engines were installed and affords an excellent example of how gas poisoning and fires may be caused by the carelessness and ignorance of those in charge.

The storage of petrol in dugouts required the most careful supervision on account of the danger of fire.

Later practice in dugout construction where petrol engines were employed did away with most of the difficulties which have been described. Exhaust pipes were duplicated and made of 4-in. steel pipe concreted into 6-in. vertical bore-holes, the exhaust being connected by a T-joint to the pipe and the bottom of the pipe closed by a screwed plug in order that soot and condensed vapour could be removed from the pipe with ease. Petrol was stored in locked cupboards, each cupboard being lined with tin sheets. Engine-houses were largely secured by steel joists as props and beams, the spaces in the roof, floor and sides being filled in with expanded steel and concrete.

Poisoning by Lachrymatory and other Warfare Gas in Mines.—The Germans attempted on several occasions to render the allied galleries untenable by exploding lachrymatory bombs which were placed among the high explosive. As a result, fumes with an intensely lachrymatory action as well as CO were produced. Experiments carried out at one of the mine schools showed that when a charge of ammonal, in which was placed a number of lachrymatory bombs, was well tamped before being fired there was little lachrymatory effect, but when the charge was slightly tamped or fired without tamping lachrymatory action was quite marked.

As the goggles supplied with the Proto apparatus did not give sufficient protection, all mine rescue stations were supplied with sponge rubber goggles, which at first were found very effective. Later, as it was found that these in the presence of strong concentrations allowed gas to penetrate, Salvus sets were fitted with the mask of the gas respirator. These afforded perfect protection against all irritant gases as well as against CO.

In connection with the use of lachrymatory gas in mines, it is interesting to note what must be considered one of the most extraordinary incidents in the war, and quite unique in warfare, namely, the flooding of the Béthune coalfield with lung irritant gas by the enemy.

Although one of the collieries (Fosse 8) in this very important mine system was in the enemy lines, and all the shaft-heads and the mining villages of Philosophe, Annequin, Vermelles, etc., were within easy range of the enemy and had been frequently shelled, the French had been able to continue working, although the output of coal had been considerably reduced.

In September 1917, at the height of the submarine warfare and when coal was urgently required by the French, the enemy made a determined effort to prevent the French from working the Béthune collieries. To prevent the flooding of the whole system, the French had installed pumps near Fosse 8, which, it should be added, was the downcast shaft for the whole system. Two miners were constantly stationed near the shaft bottom at the 240-metre level to report any attempt of the enemy to make use of this means of communication. As unusual activity had been reported at this shaft-head, one of the tunnelling companies (170th) was asked to detail a permanent guard for duty in the mine. The French miners at once commenced building a stopping, as the enemy appeared to be preparing to destroy the shaft at Fosse 8 in order to flood the whole Béthune area. The stopping was nearing completion when the enemy flooded the mine with chloropicrin, a very powerful pulmonary irritant gas. A signaller escaped and gave the alarm. Another signaller, the whole of the tunnelling company guard, and all the French miners who were at work on the stopping were unable to make their escape and perished.

Rescue parties were quickly organized by the tunnelling company and several attempts were made to reach the men, but these failed because it was found that chloropicrin was present in such concentration that after 1,600 yards had been traversed the gas came through the face-cover of the box respirators. Rescue operations at this stage were rendered more difficult by the enemy shelling the shaft-heads in our lines with gas shells. One of the rescue parties on coming to the surface was exposed to this, and all the members were more or less seriously affected, the officer in charge of the party dying next day from the effects.

Special respirators were now improvised, the masks and drums of which could stand prolonged exposure to high concentrations of gas. After several attempts rescue parties recovered all the bodies. Strenuous efforts were now directed to clearing the mine of gas in order to permit of the French miners completing their task of sealing off Fosse 8 from the rest of the mine system. Their efforts proved successful.

A short summary of the conditions under which work was carried out by the rescue parties will give some idea of its terribly trying and arduous character :—

The chloropicrin was present in great concentration. The men had to climb many hundred feet of ladder (one shaft was over 1,000 ft. deep), to traverse long roads, to put up brattice, make stoppings and effect changes in the ventilation, and to carry bodies on stretchers. Owing to the length of the roads, sometimes two or more miles, to be traversed, the men were exposed to the gas for a considerable time. The light underground was very defective; this called for the best possible type of eye-piece. Any eye-piece which dimmed readily was a danger, as in this class of work the roads were frequently bad, and unless clear vision was possible such accidents as falling down winzes,* a clear drop in this case of 80 ft., might occur. The experience gained in these rescue operations pointed to the necessity of the officer in charge of the party personally supervising the cleaning of the eye-piece of each member of the working party.

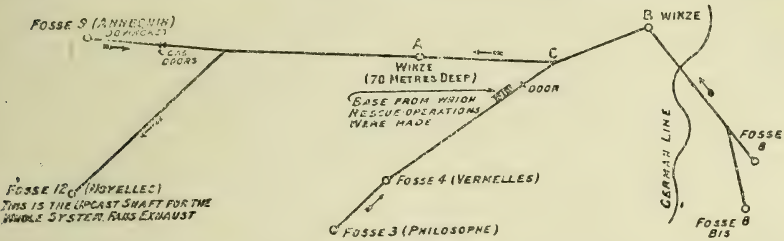

Fig. 5.—Sketch-plan of the Béthune Colliery System. Not to scale.

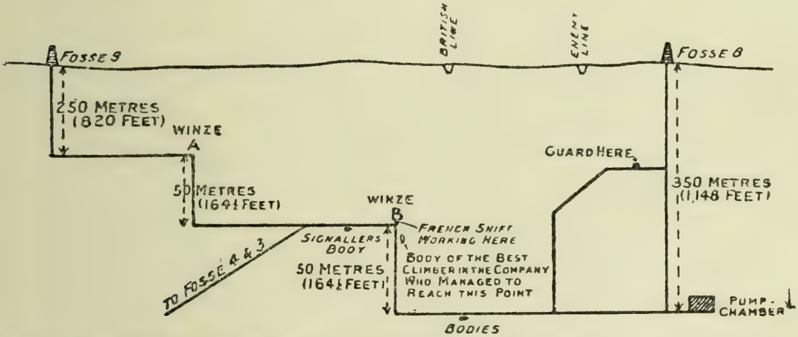

Fig. 6.—Diagrammatic Section on a Line between Fosse 9 and Fosse 8.

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* A winze is a small shaft sunk from one level to another.

Although the gassing of the Béthune collieries resulted in regrettable loss of life, the enemy failed to achieve his object of flooding the mines by first gassing the guard and preventing the carrying out of any work in the mine, and then breaking the tubbing of the shaft in his line. Owing to the wonderful resource, devotion to duty, untiring efforts, and bravery of the tunnellers, who all realized what the loss of these collieries would mean to the allies, a dangerous situation was saved and a most valuable coalfield preserved.

In this connection it may be remarked that gas doors frequently proved of the greatest value in isolating sections of a level or for cutting off upper-level attack galleries from deep "backing-up" galleries from the same shaft. The following incident shows how they acted in preventing a mine system being flooded by mine gas from an enemy camouflet :—

> The enemy fired a camouflet, but as it was stand-to time in the trenches no men were underground and the gas door leading to the gallery involved in the blow was closed. About half an hour later a rescue man went down with a canary ; the latter was quite unaffected until the gas door was opened, when it immediately collapsed and the Proto man returned to the surface. He and another rescue man were at once sent down to take the air-line into the face and leave the door open to clear the affected gallery of gas, a man being kept on the blower at the surface. After about two hours the man on the blower was affected by the gas, but without serious result. In this case the door, when kept closed, confined the gas to the one gallery and would have enabled any men in other parts of the mine system to make their escape.

The following was one of the first occasions on which gas doors were used :—

> It was expected that the enemy would blow a camouflet against a certain gallery. As it was absolutely necessary for work to proceed in the neighbouring gallery, it was resolved to erect a gas door, and, in order to break the force of the explosive wave, five sand-bag screens with air spaces between were also erected. When the mine exploded three tunnellers were at work in the neighbouring gallery. They made their way to the surface in safety. Proto men went down and found the gas door in position and effective ; three of the sand-bags were blown down, one was hanging damaged, and the other unharmed.

Deep dugouts for the infantry, communication tunnels, etc., should if possible be entirely isolated from the mine system. Where this was impossible orders were given that they should be protected by double gas doors, no matter whether they were connected with the upcast or downcast, as gas frequently takes vicarious routes after the ventilation has been disturbed by a blow. Where these precautions were neglected accidents occurred. Orders were also given that machine gun emplacements must never be connected with the shafts.

Poisoning from Deficiency of Oxygen in Mine Air.—The symptoms produced by working in very badly ventilated galleries are due to deficiency of oxygen. Increase of CO_2 in the quantity met with in mines will not produce serious results. The best guide is the effect on candle-light. Regarding this, it was found necessary to issue a word of caution because miners are very prone to regard as harmless any air in which a candle will burn. They were warned that the presence of CO in the atmosphere had no effect on the flame of a naked light. When old workings were reopened, or when old enemy galleries or British galleries were broken into, it was frequently found that the air was so bad that candles would not burn. Companies were notified that in such circumstances the oxygen content might drop perilously low, and work should never be carried on with electric lights unless in cases of the greatest urgency. In such an atmosphere the presence of a very small percentage of CO might cause serious poisoning.

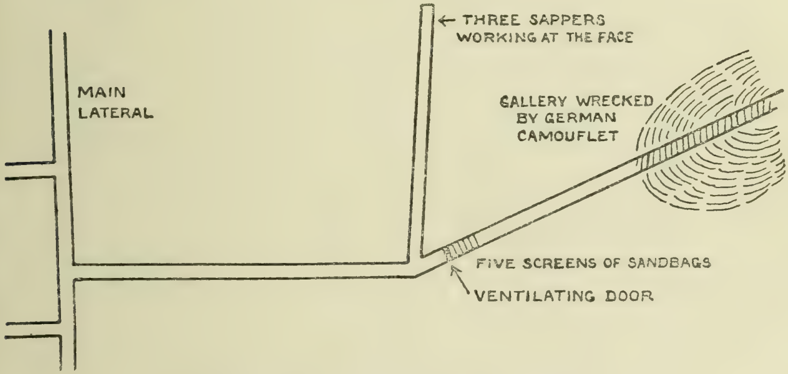
THREE SAPPERS WORKING AT THE FACE
MAIN LATERAL
GALLERY WRECKED BY GERMAN CAMOUFLET
FIVE SCREENS OF SANDBAGS
VENTILATING DOOR

Fig. 7.—The use of gas doors in mining.

In the early days of mining, owing to the small size of the galleries, considerable trouble was experienced in obtaining good ventilation. The same trouble was met with at the working face in driving deep dugouts, subways, and galleries in mines before the galleries had been connected up and natural ventilation established. When work was persisted in for any length of time in bad air the men became drowsy and listless and efficient work became impossible. When tamping of the charge was being carried out in very small galleries great difficulty was experienced owing to the fact that a number of men were required to handle the bags which were passed from man to man, so that the air became very much worse than when driving galleries.

CO_2 may be given off from the ground in which galleries are driven. This was found to occur in a mine under the La Bassée

Railway at Cuinchy, where the ground was a variety of mudstone. Considerable difficulty was experienced with the air as the distance from the face of the shaft increased, and special care had to be taken in sealing all joints in the air pipe in order to get sufficient air delivered at the working face. Work had frequently to be suspended on account of the state of the air but, the danger being recognized, no ill-effects resulted.

After the retreat in March 1918, when the enemy was held on the Amiens front, shelter from shelling and bombing was urgently required. To supply this many old caves were opened up. These were underground quarries where the hard chalk had been mined for building purposes. In a number of these the entrances had been sealed for many years. The danger of exploring the caves without testing the conditions of the air was recognized by the tunnelling officers and men ; but in certain instances sufficient precautions were not taken and therefore accidents occurred. The manner in which men were overcome pointed to a serious decrease in the amount of oxygen, this having been gradually depleted by the presence of oxidizable matter in the caves. The conditions met with were similar to those found in old shafts and old workings in collieries and in disused wells. Formerly CO_2 was regarded as the poisonous factor in these conditions, but it is now known that it is the serious deficiency in the amount of oxygen which is so dangerous. If it were CO_2 the men would receive early intimation of the danger by the onset of certain symptoms. Where the oxygen percentage was very small, men dropped unconscious, "*foudroyés*," almost as soon as they were exposed to the air of the cave. In other cases where the oxygen percentage although dangerously low permitted breathing for a certain time, the action was most insidious. The first symptoms to develop were giddiness and loss of power in the limbs ; in such cases any attempt at exertion might cause loss of consciousness.

It was found that, where men were exposed to an atmosphere the oxygen content of which, although considerably lowered, yet permitted work to be carried on and did not cause any evident distress, they felt unwell next day and complained of headache, sickness, and malaise. These symptoms are identical with those seen in CO poisoning. In cases where men were overcome in caves, if they were rescued at once they generally recovered. The important factor is the length of exposure, that is to say, the length of time the tissues are deprived of oxygen ; the longer the time the more likely are complications to ensue. The companies carrying out this work were warned of the dangers of asphyxiation and were supplied with rescue apparatus and oxygen reviving sets. Thorough ventilation of the cave before attempting exploration was, of course, the real preventive measure.

Although mice and canaries are so valuable in the detection of CO, these small animals cannot be employed as indicators of oxygen content in any atmosphere, because they do not collapse from oxygen deprivation much earlier than do men themselves. It has been proved that canaries are slightly more susceptible to want of oxygen than mice are.

Poisoning by Nitrous Fumes.—It has been demonstrated from analysis of the air of mines after explosives have been used on a large scale that nitrous fumes are present in such small amount as to be of comparatively little importance. The danger from these fumes in the proportion usually present in mines, compared with that from CO, may be regarded as very slight.

It is only immediately after a blow, and then only when there has been incomplete detonation of part of the charge, or more particularly where burning of the explosive has taken place that nitrous fumes are formed in sufficient quantity to cause serious symptoms of poisoning. The fulminant type of nitrous posioning was never met with in mining at the front for this reason, that when nitrous fumes are formed in large quantity CO is also present in such percentage as quickly to cause death. Occasionally miners who were in the galleries at the time of an explosion have shown signs of irritant gas poisoning, while the men who rescued them were quite unaffected owing to the rapid disappearance of these fumes which occurs in chalk and moist workings. Nitrous fumes are very soluble in water, and are actually a mixture of the oxides of nitrogen.

Nitrous fumes are a very treacherous and most insidious poison, and very short exposure to very small quantities may produce serious symptoms ; indeed, if the poison is present in such amount as will give rise to slight irritation of the eyes and throat, very serious after effects may result. In poisoning by nitrous fumes, where there is little or no CO present, there is generally a latent period of a few hours' duration, where the patient is quite free from symptoms and appears to have recovered ; this is very characteristic, but seldom seen in mining as a certain degree of CO poisoning, as evidenced by headache, vomiting, etc., was also present.

One case followed the explosion of one of the British camouflets, the explosive used being gun-cotton (wet). All those who were exposed to the atmosphere complained at first of slight irritation of the eyes, nose and throat, slight headache and irritating cough, but these symptoms were not marked and quickly passed. Afterwards a few had pulmonary symptoms and suffered from slight bronchitis, while one developed acute bronchitis. They all suffered from the effects of CO poisoning as well, some of them having been rendered unconscious. The percentage of nitrous fumes necessary to produce minor symptoms of poisoning never causes loss of consciousness at the time of exposure. In one of the earliest cases met with in the mines, a man twelve hours after exposure developed broncho-pneumonia of a very extensive type.

In severe cases the urgent symptoms set in with remarkable rapidity, being ushered in by severe pain in the chest, dry, incessant, extremely painful cough, and dyspnœa, all the signs indeed of a very acute bronchitis. This was quickly followed by congestion, pulmonary œdema and hæmorrhages, and the case generally ran an exceedingly rapid course, death supervening after a few hours' illness.

In a milder type sometimes seen in mining there was an extensive broncho-pneumonia, which set in within twelve hours after exposure to the fumes. Generally the cases were even milder, the bronchitis being limited to the upper bronchi. In these cases there was at first a constant, dry, hacking cough which caused considerable pain, a feeling of constriction in the upper part of the chest, and breathlessness. This was quickly followed by the next stage, in which the cough was softer, less frequent and less painful, and was accompanied by profuse muco-purulent expectoration. Owing to the additional effect of CO, it was found that convalescence in such cases was tedious, and the heart, although no definite lesion could be detected, remained weak for a considerable time. It was found that after the slightest exertion the action of the heart tended to become rapid, sometimes irregular, and the patient was easily exhausted. The medical officers of the tunnelling companies in which these cases occurred, who were quite familiar with CO poisoning, were struck by the fact that cardiac symptoms were more marked in poisoning by combined CO and nitrous fumes, while all the cases showed an extreme degree of prostration and were much longer " in finding their legs." There is no doubt that the combined effect of CO and nitrous fumes has a distinctly harmful effect on the heart.

Apart from their characteristic odour, nitrous fumes may readily be recognized chemically by the fact that they turn blue a paper which has been dipped in a solution of starch and iodide of potash, and slightly acidified.

CHAPTER XX.

CARBON MONOXIDE POISONING IN MINES.

WHEN an atmosphere containing CO is breathed, the oxygen in the blood is displaced from its combination with the hæmoglobin by CO, owing to the fact that the affinity of hæmoglobin for CO is more than 250 times greater than for oxygen. With each inspiration more carboxyhæmoglobin is formed; as a result all the tissues suffer from oxygen starvation, and all the symptoms are directly referable to this anoxæmia. It was formerly taught that this combination was so stable that it could only with the greatest difficulty be disturbed; but this is not so, and although carboxyhæmoglobin is much more stable than oxyhæmoglobin it is far from being a permanent combination. The rate of absorption of CO depends upon various factors, such as the percentage volume of oxygen present (where this is small poisoning will be much more rapid), and the susceptibility of those exposed. The rate of dissociation of CO from the blood is also determined by the partial pressure of oxygen and CO in the air breathed. When a man is removed to the fresh air the CO gradually disappears from the blood, and much more quickly in the presence of oxygen; its displacement, however, is much slower than its absorption. The symptoms of CO poisoning depend upon the percentage of red blood-corpuscles thrown out of action by combination with CO. If the exposed person is doing hard work, symptoms of slight giddiness and shortness of breath may appear when only 20 per cent. of the hæmoglobin has been fixed by CO. During rest distinct signs of poisoning appear when 30 per cent. of the hæmoglobin has combined with CO. With every increase up to 50 per cent. the symptoms become more decided, staggering and unsteady gait, confused cerebration and loss of consciousness ensuing. In some men who are very susceptible to the action of CO a smaller degree of saturation may be sufficient to cause loss of consciousness. Examination of the blood of a number of men taken out of mines, who had been killed by CO, showed considerable variation in the amount of hæmoglobin saturated by CO, the amount varying from 54 to 82 per cent. Most showed 70 to 80 per cent. Men who were killed by the same explosion showed considerable difference in CO saturation. In one man who was sufficiently far from the seat of explosion to have escaped injury by the explosive wave, but who was found dead, there was only 20 per cent. CO saturation. The explanation of this is that the man died from breathing de-oxygenated air with CO under pressure, the air of that part of the gallery having been replaced by the products of combustion from the exploded mine. In men who have survived sufficiently long to breathe fresh air, or who have had oxygen administered to them, the degree of CO saturation may be found to be much less.

In mine gas poisoning there were frequent demonstrations of the cumulative action of CO. Although there is only a small percentage of the gas in the air, it will be gradually and continuously absorbed by the blood until distinct symptoms of poisoning are produced. The amount finally taken up depends upon the relative concentration of oxygen and CO in the air breathed, so that the blood can only be saturated up to a certain point, no matter how long exposure may be. For example 0·02 per cent. CO in the air will never produce loss of consciousness, but tunnellers who worked in such an atmosphere frequently complained of headache at the end of their shift, and it was also found that their output of work decreased considerably. According to Professor J. S. Haldane, 0·04 per cent. CO in the air will produce 34 per cent. saturation of the blood; 0·05, 46 per cent. saturation; 0·06, 52 per cent. saturation; and 0·08, 58 per cent. saturation. Even after prolonged exposure to such quantities recovery was general. Anything above 0·1 per cent. CO is dangerous to life. It is this cumulative action of CO which makes it such a dangerous and insidious poison. For example, it will permit those who are attempting rescue work without apparatus to penetrate a certain distance into a mine without being affected, but a point will be reached when sufficient CO has accumulated in the blood to cause symptoms of poisoning to appear. The affected men now realize their danger when it is too late, as there is too little oxygen available in the blood to carry them to a point of safety before loss of consciousness supervenes. In the same way, when any man was obliged to come out of the mine owing to feeling the effects of the gas, his blood was already dangerously saturated with CO, so that should he descend again only a very short exposure would be necessary to render him unconscious. These points are very important to remember in rescue work. In the early days of mining a considerable percentage of the casualties was among men who rushed in without apparatus to rescue their comrades. Certainly the restricted length of galleries as compared with colliery workings at home was a great temptation to the men to attempt rescue without apparatus. The order, " No man is to descend the shaft without rescue apparatus till the mine is reported clear of gas," which was early issued, resulted in a noticeable decrease in the number of casualties.

The consumption of oxygen varies very greatly according to the amount of work done by the wearer. At rest a man consumes 250 c.c. of oxygen per minute ; when walking at a slow rate, 1,200 c.c. ; walking quickly, 2,000 to 2,500 c.c. ; and violent exertion, 3,000 c.c. It was difficult to persuade the mine rescue men wearing apparatus that more oxygen was required when walking quickly than when doing hard work with their arms alone. The following remarkable illustration of the value of conserving oxygen consumption in entombed men is interesting :—

> In the Ypres salient the enemy blew a mine which destroyed several hundred yards of a British gallery that was well under the enemy line. Twelve men were in the mine at the time. A rescue party organized immediately found, after working for a day, that the armoured hose for carrying air to the working-face and the electric leads for lighting had been injured. After eight days' hard work the gallery was cleared and eleven bodies were found in the dip ; it was presumed that the twelfth had been buried. As a matter of fact, this man had retired to the working-face, where he lay down ; on the eighth day, when he found the air had greatly improved, he made his way out. The information given by this man proved to be most interesting. After the explosion he tried to dissuade his mates from attempting to dig their way through, as by doing so they would quickly consume the little oxygen available in the gallery, and it was certain that a rescue party was already hard at work. He urged the men to distribute themselves along the gallery to the working-face and to lie down, as by so doing they would consume less oxygen They refused to listen to him, so he made his way to the face, prepared a bed of sand-bags, and lay down. After the third day, when probably the eleven men had died, he found that the air had improved. He had no food, but he had a little water in his water bottle with which he rinsed out his mouth, but which he was careful always to return to the bottle. It required great strength of character on the part of this man to separate himself from his mates in such a time of danger, to go far away from them and lie down ; and it also required great confidence in his own judgment regarding the condition of the atmosphere and the factors which affected it. The man was found to be none the worse for his trying experience, the second of its kind he had undergone.

In the same way a man at work absorbs more CO than at rest, and the more strenuous the work the more CO will be absorbed and the more quickly symptoms will appear. For example, if a miner at rest were exposed to 0·1 per cent. CO, it would take two hours for symptoms of poisoning to develop, whereas at work the same percentage would cause symptoms to appear in forty-five minutes. 0·2 per cent. causes loss of consciousness in twenty to thirty minutes in a man at work, and

0·3 per cent. in ten to fifteen minutes. Advantage of this fact was taken by one of the officers in charge of mine rescue schools, who taught his rescue men to train white mice to climb actively over the hands, and to use this method when testing the air of a suspected place.

A man feeling himself becoming affected with gas naturally rushes from the danger zone to the bottom of the nearest shaft. Men were taught whenever they were exposed to gas to proceed as quietly as possible out of the galleries, making as little exertion as possible in order to conserve the oxygen supply in the blood. In all rescue operations it is important, then, to see that there is no haste, and that men who have been gassed are brought quietly along. It was found that anxiety, excitement, or marked mental effort act in the same way as excessive muscular exertion, all hastening the absorption of CO.

Analysis of the air in badly ventilated galleries after blows in which men had been poisoned showed that under these conditions the action of CO was intensified, and that symptoms of poisoning appeared early. This was probably more the result of the decreased oxygen than the increase of CO_2. Not only so, but percentages of CO, which, in ordinary circumstances, would cause only discomfort, might under such conditions produce dangerous symptoms. In men who have been found dead near an explosion, but sufficiently far not to have shown effects of violence, death was due in some cases to the combined action of CO under pressure and want of oxygen, the oxygen having been displaced by the products of combustion of the explosive used.

It is well known that prolonged oxygen starvation has a very serious effect on nervous tissue. Experience of mine gas poisoning similarly proved beyond question that prolonged exposure to small quantities of CO is much more injurious to the system than short exposure to large percentages. A man who has been exposed to a very high percentage of CO may recover ; hence the order given to mine rescue men to take, whenever possible, oxygen reviving apparatus into the mine after explosions. It was also found that, after prolonged exposure to comparatively small percentages of CO, relapses after apparent recovery were very common, and that serious after-effects developed and sudden death occasionally occurred ; whereas, after short exposure to high percentages, when the patient recovered consciousness a perfect recovery generally followed. The after-effects of CO poisoning are not due, as is commonly believed, to retention of CO in the blood, but to the organism being deprived for a time of a considerable percentage of oxygen. As soon as an atmosphere free of CO is breathed, the CO in the blood is gradually replaced by oxygen. Even in serious cases it seldom takes longer than three or four hours for the blood to be thoroughly free of CO, and this period can be considerably shortened by the administration of oxygen.

Individual susceptibility plays a very important rôle in CO poisoning, some men being much more susceptible than others. Experience showed that some men could work in an atmosphere that would quickly knock out others who were more susceptible. When such men were overcome they seldom suffered from the distressing after-effects and made rapid and complete recoveries whereas in more susceptible men who had been several times gassed heart trouble often ensued. It was also found that young men were more susceptible than men over forty, owing to the deeper inspirations and greater elasticity of the chest permitting more rapid absorption of the gas. Men who were addicted to alcohol or who had recently recovered from a drinking bout, as in the case of some men who had just returned from leave, were usually very susceptible to CO, and the after-effects were more severe, mental disturbances frequently being marked.

A number of the specially enlisted miners suffered from bronchitis and asthma. In the early days of mining, when the galleries were small and much less efficiently ventilated, impure air (decrease of oxygen and increase of CO_2 with traces of CO) was a potent factor in precipitating attacks of bronchitis and asthma. It was also found that these men were so susceptible to CO poisoning that an order was issued prohibiting them from working in any place where the presence of gas was suspected. Apart from this, coughing, of course, was a danger in places where silent working was necessary. A considerable percentage of the miners from Australia and South Africa, more especially the older men who had worked in the gold-mines, suffered from silicosis. This rendered them more susceptible to CO ; they suffered more severely from the effects and took longer to recover.

It was also found that the functional power of the heart is a decisive factor in a man's ability to stand CO poisoning. Men suffering from heart disease were unusually susceptible. Men who had any inherent weakness of the nervous system were also more susceptible to CO, and if affected were likely to develop certain nervous disorders. In such even a short exposure to CO might result in neuritis, and marked mental disorders such as delirium.

It is known that obesity predisposes to CO poisoning. Captain Rutherfurd, one of the medical officers of tunnelling companies, thinks that this is owing to the fact that human fat dissolves CO and so provides a reservoir of this poisonous substance and keeps up the poisoning.

It was found that, where men were continually working in galleries, the air of which contained a small percentage of CO (*e.g.*, 0·02 or 0·03 per cent.), a certain amount of toleration to CO was established ; and, when these men were exposed to larger quantities, longer exposure would be necessary before they were overcome than would be the case in others in whom this partial tolerance had not been established. Such men, however, lost this tolerance after they had been working in good air, or after they had been back in rest billets. It cannot be insisted on too strongly that CO is no respecter of persons, and that immunity from CO does not exist.

Symptoms.

That CO has a very varying effect on those exposed to its action was well demonstrated when, as happened on various occasions, a number of men had been exposed to the same atmosphere for the same time. It was also proved that the symptoms were at times most indefinite.

If the atmosphere contains a large quantity of CO, or where the percentage of oxygen has fallen and there is increase of CO_2, and CO is present in certain amount, as happens when men are caught in a mine when an explosion occurs, loss of consciousness will develop in a few minutes with practically no warning. It was much more common, however, to find smaller percentages of CO present ; on exposure to such an atmosphere the onset of symptoms is gradual and insidious. The first symptom complained of is slight giddiness or lightness of the head, accompanied by noises in the ears, indistinct vision and a feeling of fatigue or weakness ; this is followed by dyspnœa and palpitation, which are aggravated by the least exertion, and confused cerebration, quickly followed by the characteristic loss of power in the limbs which leads to staggering. All these symptoms are the result of cerebral anoxæmia. When this stage has been reached, the saturation of the hæmoglobin by CO has proceeded so far that it is too late for the man to reach a place of safety, as the least exertion will lead to loss of consciousness. In others most of the above-mentioned symptoms are absent, and the first symptom drawing attention to the dangerous character of the atmosphere is the utter weariness and powerlessness of the legs, which sometimes feel as if they do not belong to the patient, while in others the arms are affected. In such cases the men may be fully conscious of the danger, but are unable to escape. In the early days of mining a number of fatal accidents occurred owing to men who had been slightly gassed making their way out of the mine by climbing the vertical ladder in the shaft or walking up a steep incline, thus greatly increasing the demand on the already impoverished oxygen content of the blood; this led to powerlessness of the limbs and feebleness of grip, perhaps loss of consciousness, resulting in the men being precipitated to the bottom. Orders were at once circulated that no man, however slightly gassed he might seem, should ascend the shaft without being roped and hoisted, and that life-lines should be kept at each shaft. At that time another danger was not properly appreciated, namely, that exposure to fresh air often rendered unconscious men who had slightly recovered from gas poisoning, so that after gaining the shaft-head they fell back unconscious and were killed. Sensory disturbances were occasionally met with, and miners have declared that, when ascending the ladder after they have been gassed, the rungs and sides of the ladder felt as if they were two or three times the usual size, and that their feet were placed on some soft yielding substance. In such cases there was also slow cerebration.

In a small percentage of cases the first symptom is a feeling of intoxication, exaltation or exhilaration, the judgment and temper being affected, while others appear as if they were in the early stages of alcoholic intoxication, laughing immoderately, swearing, singing or shouting, and becoming quarrelsome. It was found that when these patients regained consciousness there was frequently a return of the above symptoms, and, in some, delirium. In other cases the onset is more insidious, the man either dropping without any warning, or becoming languid, drowsy with an irresistible desire to rest; the mind also becomes so quickly blurred that unconsciousness develops before the man is able to appreciate the danger. Owing to the abovementioned mental disturbances men were prohibited from doing any work (*e.g.*, listening, pumping) when alone, where there was any suspicion of gas. The insidious effect of breathing a CO-laden atmosphere cannot be over-emphasized. Warning symptoms cannot be relied upon. In some cases, as has been noted, these may not occur; in others, although present, they may not be appreciated owing to judgment, reasoning and discretion being so quickly impaired; while in many cases collapse follows so rapidly on the appearance of the danger signals that escape is impossible.

The effect of CO on respiration is quite characteristic. At first there is increased frequency of breathing, which later becomes much slower. In serious cases it may be very superficial, slow and interrupted by pauses. When the breathing is of this type relapses are frequent, and the patient must be carefully watched. It was wonderful how quickly some of these cases responded to the exhibition of oxygen. After a few minutes the movements of the chest wall, which before were hardly perceptible, became deeper and the pauses disappeared. If the administration of oxygen was combined with artificial respiration, which materially improves the chest movements, the effect was greatly increased and the results obtained were more permanent. Cheyne-Stokes respiration was not infrequently seen. Two of the tunnelling medical officers who had seen cases of this were struck by the fact that these patients all showed marked cerebral symptoms, great excitement, delirium, extreme restlessness, etc., when they recovered consciousness. Of cases noticed in which Cheyne-Stokes breathing existed, two-thirds died, probably as the result of the medullary centres being affected.

When coma has been deep, râles are frequently found in the chest. These are nearly always to be found where convulsions have occurred, in which case coma is very often profound.

The pulse-rate in the large majority of mild cases was found to be between 80 and 90 per minute. This is also what is found in the preliminary stages of poisoning, but as the case gets worse the tension falls and the pulse becomes rapid and weak. In a considerable percentage of the men found in an unconscious condition the pulse rate was very slow, between 50 and 60. Occasionally it was remarkably slow, *e.g.*, 30, which was the pulse-rate of a man who was discovered in a mine after a blow in a deeply unconscious condition, frothing at the mouth, with the arms rigidly crossed over the chest, and who shortly afterwards developed a convulsion. Marked irregularity of the heart has also been noted, accompanied by palpitation and a feeling of faintness.

One of the most characteristic effects of CO is lowering of the body temperature. Even in mild cases the patient complains bitterly of cold, and, if the extremities are examined, they will be frequently found to be icy cold; while in serious cases, where the patient has been unconscious for some time, the surface of the body is also very cold. In the trenches this added to the difficulties of treatment, especially if the shafts and galleries of the mine were wet. In many cases where the temperature was taken it was found to be subnormal. The fall of temperature is brought about in two ways: In the first instance, owing to the combination of CO with hæmoglobin, the tissues are deprived of a considerable percentage of oxygen, which is intensified by the indirect action of the weakened circulation. This produces decreased oxygenation, and thus decreased metabolism with decreased production of heat. Secondly, the heat-regulating nerve-centre in the brain may be seriously affected by the deprivation of oxygen. Later on, when the patient is recovering, a rise in temperature with rapid, bounding pulse is met with.

Convulsions were frequently seen; and the appearance of a number of the bodies was very suggestive of death having occurred in a convulsive seizure. Men were occasionally found frothing at the lips, with the face leaden in hue, and the arms and legs quite rigid. In some of these cases the pupils were widely dilated, in others unequal, and in a few contracted to a pin-point.

The colour of the face varied very much, in some cases depending upon the rapidity of asphyxiation. Where this had been rapid, the face frequently had a leaden tint; this was also seen in cases where coma had been profound. In such there was froth (thick mucus often tinged with blood) about the mouth. In other cases the face was pale and bedewed with perspiration, while in a considerable number of cases the cheeks were pink and the lips of a vivid carmine tint. In those who have died of CO poisoning this sometimes gave the face a wonderfully lifelike appearance.

On recovering consciousness from CO poisoning men very often appeared quite dazed and stupid, and frequently had no recollection of what had happened. Their minds were confused and they had great difficulty in answering questions. In some cases speech was affected, being blurred, slow and indistinct, and occasionally there was constant repetition of certain words and sentences. The dull, heavy countenance, the difficulty in getting co-ordination of thought, the confusion of ideas, and the defect of speech gave some of these cases the appearance of being drunk.

Some patients, on recovering consciousness, became very drowsy, great difficulty being experienced in rousing them.

Later on in such cases the mental condition changed, and an irritable phase developed, when they were intensely wide awake, insomnia becoming a troublesome feature. Others, again, on regaining consciousness, became apathetic and listless, but it was much more common to find wild delirium and excitement, the patient becoming very aggressive, struggling, fighting and throwing himself about, swearing and shouting incoherently, or laughing or crying, while a few would behave in the most childish, silly fashion. A number of accidents occurred to mine rescue men owing to the nose-clip or mouthpiece of their apparatus having been torn off by a struggling patient. The mine stretcher proved very useful in removing such men from the mine. The quarrelsome, aggressive mood might last for a considerable time ; this was recognized by the Germans, who drew attention to the fact that it might lead to defiance and breaches of discipline. Wild delirium was frequently followed by an apathetic state. The following case, described by Captain Stephenson, one of the tunnelling medical officers, shows this change and also some of the prominent mental disturbances mentioned above :—

> The patient had been in a mine during an enemy explosion and had been rendered unconscious. On regaining consciousness there was wild delirium. When seen by the medical officer the patient was semi-conscious, there was slow muttering delirium, the pulse and colour were good. On admission to the field ambulance the patient complained of severe pain in the abdomen, was very cold, temperature being 97·8, pulse 70. Next day he was very quiet, his countenance was vacant and apathetic, there was slow cerebration, practically complete loss of memory, and constant reiteration of the words, " It's only my back." After great difficulty the medical officer managed to get co-ordination of thought, and replying to a question he said, " Mine, sir." Anarthria was marked, the patient making great efforts to talk, but failing. There was slight twitching of the muscles of the arms, and movements of the fingers suggestive of rolling paper. The legs were slightly stiff, and he resisted bending of the knees. There was slight hyperæsthesia in the lower legs, and the knee-jerks were slightly exaggerated.

Some of the more prominent initial symptoms persisted for varying periods. The most common of all was headache. which was very persistent and intractable, of a very intolerable type, and frequently so intense as to cause vomiting. It was generally of a peculiar throbbing character with a feeling of constriction as if a band were tied rightly round the head, and it was always made worse by stooping, or by any muscular exertion. It was often associated with giddiness and vomiting. These migrainous attacks are most characteristic of CO poisoning. Giddiness generally disappeared early, although in some cases it persisted for a few days or longer, even when the patient was lying in bed. Vomiting, with pain and a feeling of fullness or distension about the epigastrium, was frequently seen, and this might last for several days in spite of treatment. It was probably the relief from the pain gained by vomiting which prompted the exhibition of emetics, an old method of treatment against which the men were warned. Obstinate hiccough was also occasionally met with. In a smaller percentage of cases there was diarrhœa with colic, occasionally accompanied by the passing of blood; this generally passed off in a day or two. Such cases were much more common when the men were exposed to CO poisoning in a gallery where the ventilation was bad, that is to say, where there was decrease of oxygen and increase of CO_2.

Some of the medical officers carried out systematic examination of the urine, and it was shown that if this is done within a few hours of poisoning the presence of sugar might be detected. This generally disappeared in twenty-four hours, but in certain cases lasted longer. Albuminuria was sometimes met with, but it never persisted for any length of time.

Attention has already been called to the action of CO in lowering temperature. When the patient is recovering there may be pyrexia, which may be high and last for a few days. The following is an example :—

An Australian tunneller was seriously gassed, being unconscious for a considerable time. He was removed to hospital, and three days later his temperature, from being normal or subnormal, reached 104°, and the pulse-rate 88; next day, temperature 102·8°, pulse 78; fifth day, temperature 102°, pulse 76; sixth day, temperature normal, pulse 72. Patient complained of great pain in the left side and over the stomach; there was no area of dulness in the lungs and nothing to explain the temperature. He made a good recovery.

A number of cases similar to the above could be quoted. The thoracic pain complained of in this case is a not infrequent after-effect of CO poisoning.

After-effects.

The Cardio-vascular System.—It has already been shown that the functioning power of the heart has an important bearing on the susceptibility to CO poisoning; also that men who had any functional or organic disorder of the heart were peculiarly susceptible to this poison. The after-effects which were most commonly met with and which persisted longest were the cardio-vascular. It was frequently found that the immediate symptoms of cardiac disturbance did not become prominent till after exposure to the fresh air, or after exertion; hence the great value of rest in treatment. There were many cases in which there was tachycardia, breathlessness, palpitation oppression about the chest and precordial distress, uncomfortable throbbing of the head, and of the large vessels, the more especially in the neck (in some cases the action of the heart was so tumultuous that the patient held his chest with his arms in order to allay the distress) ; but not the slightest dilatation nor any organic lesion of the heart could be detected. In these cases any slight exertion might bring on giddiness, headache, principally frontal, feeling of faintness, flashes of light in the eyes or dimness of vision, noises in the ears, all of which are the result of disturbance of the cerebral circulation. Although no cardiac lesion could be detected in these cases, in some the heart sounds pointed to weakness of the heart muscle, probably as the result of the action of CO on the nervous mechanism of the heart. In all these cases the most prominent symptom was tachycardia, which was particularly persistent and was noted many months after gassing. In a considerable number of these heart cases following CO poisoning the patient when at rest appeared quite normal, making little complaint unless of weakness and depression ; the pulse was often normal but on the slightest exertion, *e.g.*, a short walk of 50 yards, the pulse-rate rushed up to 120–150, and the patient came in quite exhausted and blown, frequently complaining of frontal headache. In some cases there were paroxysmal attacks of tachycardia for no apparent reason. In one man who had been repeatedly gassed the pulse-rate was 145 to 150. These attacks were generally accompanied by breathlessness, a feeling of faintness, and in some by a feeling of impending death ; after the attack the patient was very depressed, quite devoid of energy and often quite lifeless. In some there were acute attacks of dyspnœa, which also appeared for no apparent reason. Another man complained of waves of heat, marked dyspnœa, great precordial distress, palpitation, and tachycardia (140 per minute).

After CO poisoning, more especially after repeated exposure, some men developed cardiac mischief, and cases of slight dilatation were frequently met with. In one patient, an officer, repeated exposure to CO lit up old cardiac trouble, causing acute dilatation.

Attention has already been called to marked slowing of the pulse in men who were found unconscious in mines after explosions. In a number of cases the bradycardia persisted for a considerable time, pulse-rates of from 32 to 50 having been noted. This condition was not nearly so frequently met with as tachycardia.

In all cases of cardiac disturbance following CO poisoning convalescence was very slow, months frequently elapsing before complete recovery.

The Blood.—The condition of the blood after serious poisoning by CO has been found to be very varied. In a number of cases anæmia, with decrease of corpuscles and the hæmoglobin value, developed. But polycythæmia was frequently noted, the number of red corpuscles occasionally being increased to over 7,000,000. With this increase of red corpuscles the hæmoglobin percentage might (*a*) remain unaffected ; (*b*) be increased, in some cases to nearly 140 per cent., which was the more common ; or (*c*) be diminished, in some cases to 80 per cent. Again the hæmoglobin value might be considerably increased with no change in the number of corpuscles. Lastly conditions similar to those found in the blood of men exposed to rarified air have been noted—the presence of many poikilocytes and microcytes, increase of red corpuscles and of the hæmoglobin percentage. In many of the cases where increased hæmoglobin value was found, certain cardio-vascular symptoms were generally met with, of which the most prominent were tachycardia and breathlessness. Where the percentage was high, tachycardia was almost invariably present. In certain cases exertion was required for its development. It was found that the hæmoglobin percentage as well as the pulse-rate varied considerably. In many a peculiar mental condition, characterized by depression and apathy, was noted, and great weakness and loss of energy were general. It was rare to find in cases where the hæmoglobin value was high that the pulse-rate did not increase on exertion. In all the cases convalescence was very tedious and the patient remained weak for a long time. The following are a few typical cases :—

A tunneller, aged 35, was dragged out of a mine in a comatose condition; he remained unconscious for two hours. Examination of the blood was made twelve days after, when the hæmoglobin percentage was found to be 118. The pulse-rate was 80, and was not much affected by exertion. He complained of great weakness, frequent headaches, occasional giddiness, and he was very depressed and quite uninterested in what was going on around him.

Another tunneller had been working in tainted air for a few weeks, the amount of CO being just sufficient to cause headache and giddiness at the end of his shift and when he was exposed to the fresh air. One day he was rendered unconscious by a sudden inrush of gas. Twelve days later he still complained of headache, general weakness, and indefinite pains in the legs. Tachycardia was well marked and was accompanied by breathlessness and vertigo. There was also a small but constant rise of temperature, which was variable but never over 100°F. On standing up quickly there was a marked fall of blood-pressure and the patient complained of vertigo. Like most of these cases he was very depressed and devoid of energy. The hæmoglobin percentage varied between 120 and 132.

Captain Geoffrey Marshall gives the following report of a case :—

> " The patient was admitted to field ambulance in a ' hilarious state ' after being gassed in a mine and revived by oxygen apparatus. He remained at the field ambulance for nine days and was then transferred to No. 17 Casualty Clearing Station. On admission his appearance was healthy and he was able to walk, but his mental condition was childish ; he was unable to tell his name or unit, he wept when told to cross the room, and said, ' Doctor, I love you.' Hæmoglobin 150 per cent. ; systolic B.P. 108 mm. ; pulse-rate 84. He was unfortunately evacuated before further observations could be made."

Pneumonia.—CO poisoning must be regarded as a very potent factor in predisposing to pneumonia. A considerable number of cases were reported. In most of these exposure had been prolonged and the percentage of CO in the air, although not large, was sufficient to cause prolonged oxygen starvation of the lung and nervous tissues. Pneumonia rarely developed in cases of fulminant poisoning where exposure to high percentages of CO had been very short. The action of CO in lowering temperature was frequently intensified by exposure to cold and wet in the galleries and trenches.

The following are the chief characteristics of CO pneumonia. It develops within four days of exposure to the gas ; it is nearly always lobar, unless when caused by nitrous fumes in addition to CO, cases of which have already been described ; it is of a very extensive type and runs a rapid course ; the pulse-rate is out of all proportion to the temperature which is frequently low ; the heart collapses with great rapidity ; the right lung is frequently affected. It is a remarkable fact that the lesions following CO poisoning are so frequently located on the right side of the body.

One case of deglutition pneumonia following CO poisoning was reported ; the patient died. He had been seriously gassed and had vomited a good deal while in a semi-comatose condition. The anæsthetic action of CO makes inhalation pneumonia possible. It was owing to this danger that the order prohibiting the administration of emetics was given.

The Nervous System.—From a knowledge of the changes in the brain and spinal cord resulting from CO poisoning, it was not surprising to find a very great variety of nervous disorders. These varied from simple neuritis to the most profound changes, such as hemiplegia and dementia. In most of the cases exposure to the poisonous gas had been prolonged and poisoning consequently severe, the patient having been unconscious for a shorter or longer period. Most of the patients who were affected made good recoveries ; only in a small percentage of cases was there permanent damage done to the nervous system.

Attention has already been drawn to one characteristic result of CO poisoning, viz., powerlessness of the limbs, more particularly the lower. This generally disappeared early, but it was not uncommon to find weakness of the legs and paresis lasting for a few days. Owing to the implication of certain muscles curious gaits, for example the steppage-gait, were sometimes produced. In a number of cases there was loss of muscular co-ordination with certain sensory disturbances, such as prickling sensations, " pins and needles," with a feeling as if the legs were dead. In these the legs felt quite cold. These signs and symptoms were commonly met with and passed off in a few days ; sometimes, however, the paresis persisted for weeks, and in certain cases became localized to a certain region, *e.g.*, the peroneal, in which paralysis supervened.

Neuritis was one of the most common of the nervous disturbances. This might be localized to a single nerve or general, involving a number of nerves, the results being very similar to the multiple neuritis following various toxic conditions, such as alcoholic poisoning. The nerves most frequently attacked were the musculo-spiral, sciatic, peroneal, post-tibial, and facial. One important characteristic of CO neuritis is that the nerve may not be attacked in all its function, that is to say, the paralysis may be unaccompanied by sensory or vasomotor disturbances, while in other cases serious sensory and vasomotor disorders without paralysis may be seen.

Paralysis in a few cases came on early, being quite apparent soon after the man regained consciousness, but it was much more common to find it developing a few days after the acute symptoms of poisoning had passed off. Occasionally it came on slowly, the paresis described above passing into paralysis ; but generally there was the free interval which will be referred to again. Paralysis usually affected groups of muscles, more rarely single muscles, as, for example, the deltoid. The right side was more commonly affected than the left, and, as in the case of alcoholic neuritis, the entensor muscles more frequently than the flexor, the places most commonly affected being the extensor muscles of the forearm and the peroneal. The paralysis was usually asymmetrical and very varied in type and sometimes widely spread, several nerves being affected, while the disorder frequently jumped from one place to another.

More extensive motor disorders may be met with such as hemiplegia and paraplegia. In a number of these cases the paralysis considerably improved, and in a few days it was limited to a group of muscles. Some hemiplegias are complete and are the result of gross lesions in the brain.

One of the most remarkable cases was that of an artilleryman, under the care of Captain Tyndall, who developed hemiplegia and gangrene of the feet after being poisoned by the fumes from a brazier (CO). This man had been unconscious for forty-eight hours. When admitted to the casualty clearing station the breathing was slow, with marked Cheyne-Stokes breathing ; the left arm was rigidly crossed over the chest, the right arm being held rigidly to the side ; the left leg was also rigid. There was facial paralysis of the left side. His left pupil was dilated, whilst mentally he was in a state of hebetude. There was incontinence of urine and fæces from the day of arrival.

Disturbances of sensation such as anæsthesia, the most common, hyperæsthesia, paræsthesia, and formication were all found. Generally sensory disturbances accompanied paralysis and very often there was some trophic lesion. In many cases paralysis was ushered in by sensory disorders. In serious cases of poisoning there might be complete anæsthesia of the skin, but this quickly disappeared. Anæsthesia may alternate with hyperæsthesia and other sensory disturbances.

All the known vasomotor and trophic disorders were met with. Irregularly shaped patches of a reddish-brown colour, insensible to pricking, have been found in various parts of the body surface, also bright cherry-red erythematous patches of various shapes and sizes, more especially over the chest, buttocks and shoulders, which lasted for a considerable time and were generally followed by anæsthesia. The following is a good example of what was very often seen :—

A man was brought out of a mine in a deeply comatose condition. On examination twelve hours later two large areas, one oval shaped over the lower part of the ribs, the other irregularly shaped over the sacrum and buttock, were discovered. Both areas were raised and of a bright red colour, acutely painful and very tender to pressure. There was also paresis of the lower limbs. The patient developed pneumonia, but made a good recovery.

Sometimes these patches were found along the course of the sciatic, facial and other nerves, herpes generally developing when the facial nerve was affected. In other cases areas of a dull red colour, considerably raised above the surface, generally very sensitive to touch, although sometimes quite numb, were found over the buttock, sacrum, knees, and inner sides of arms.

Many of the cases of multiple neuritis following CO poisoning were accompanied by Korsakoff's syndrome. In such cases along with loss of memory, paramnesia, etc., there was usually considerable weakening of the mind.

Mental Disturbances.—Attention has already been called to the mental disturbances which are so frequently seen in a patient recovering consciousness. These generally disappeared in a very short time, but in some cases they persisted, and delirium, loss of memory, etc., lasted for many days.

In all those cases in which pronounced mental symptoms were encountered it was generally found that exposure to the poisonous air had been prolonged and poisoning severe, the patient having been unconscious for some time, and that very often coma was profound. In some of the cases this comatose condition lasted several days. In most cases it was also found that on regaining consciousness marked cerebral disturbance was seen, such as extreme restlessness, profound apathy, great excitement and delirium. Immediately after this subsided, and before the onset of mental disorder, there was very often a short interval of freedom from symptoms, where the patient seemed to have recovered. This was a peculiar feature of many of the cases of severe mental disturbance and is most characteristic of CO poisoning. The changes in the blood-vessels of the brain, which will be described later, will explain this phenomenon.

In the mildest cases, where mental symptoms followed exposure to CO, there were slowness of perception, confusion of ideas, defective memory, loss of all initiative and self-confidence. The patient appeared confused and thought more slowly. In other words, the mental faculties had become lowered and blunted. At the same time there might be changes in temperament, a stable and non-excitable man becoming nervous and excitable. In a considerable percentage of the less serious cases there was a certain amount of depression, a feeling of prostration and loss of vitality, which persisted for a few weeks or even longer. Headache was a prominent symptom in many of these cases. Cerebral torpor, with involuntary passage of urine and fæces, was also met with, and some of the cases presented perfect pictures of amentia. Indeed the mental changes showed every gradation up to actual dementia. In some of the cases where mental disturbances were prominent, polyneuritis was also seen.

Delirium was one of the most common of the more serious after-effects of CO poisoning. As has been pointed out, the change from profound coma to consciousness might be accompanied by furious delirium, which called for considerable restraint, and which added very much to the difficulties of rescue work in the galleries and ascending shaft and of treatment in the trenches. Occasionally this was accompanied by hallucinations.

While working a pump in a mine an Australian tunneller was overcome by gas and rendered unconscious for an hour. On coming to, he became very delirious and struggled violently. Vomiting persisted for two days; there was low muttering delirium, and the pulse, which, during the first day, was 90, dropped to 62, and remained slow. After the delirium passed off, the patient was quite silly, laughing in an inane way. Cerebration was markedly slow; he had a stupid expression; he could not explain what had happened to him; memory was very much affected. On the fourth day he became absolutely apathetic, taking no interest in anything, and it was impossible to fix his attention sufficiently long to get an intelligent answer to questions. He remained in this condition for eight days. When removed to the base he was stupid-looking, quite apathetic; there was marked loss of memory and slow cerebration, and he gave meaningless answers to questions. He made a slow, but good recovery.

A man, aged 38, was seriously gassed, being unconscious for two hours. He did not react well to the exhibition of oxygen. On regaining consciousness he became maniacal, with wild delirium; great difficulty was experienced in treating him. He was kept twenty-four hours in the trenches; during that time there was low muttering delirium, knee-jerks were much exaggerated and the pupils were unequal. He was sent to a field ambulance, where he was detained two days, being afterwards sent to a casualty clearing station. The only signs which remained on the third day were inequality of pupils and slightly exaggerated knee-jerks. He made a perfect recovery.

Most of these cases, like the second quoted above, recovered completely in a few days, but in others this state passed into one of mental weakness from which the patient recovered only after many months' illness. In such cases delirium was frequently followed by an apathetic condition, which in a small percentage of cases might develop into cerebral torpor, the patient passing into a state of dementia. Even in the slighter cases relapses were frequent before recovery was complete. Frequent headaches, with some cardio-vascular derangement, were often found accompanying the symptoms above described.

A tunnelling officer was in a mine at the time of an enemy blow and was seriously gassed. He was rescued in a comatose condition and remained unconscious for several hours. On recovering consciousness he was quarrelsome and very excited, shrieking and swearing, and talking in an incoherent manner. On admission to a casualty clearing station four days later he was conscious and could answer questions rationally, but had an absent look and was disinclined to talk; he suffered considerably from constant headache of a severe throbbing character and vomited at frequent intervals. There was complete retrograde amnesia and he could give no account of his accident. Physical examination revealed nothing abnormal. The next day he became very restless, constantly getting on to his hands and knees, moaning and groaning, and at times becoming very noisy. He could sleep only with the aid of hypnotics. His mental condition was interesting as one of dissociation. His attention could not be attracted, he took no notice of conversation, and failed to comply with any requests made to him. Indeed, he became oblivious to his surroundings and careless of his personal wants, and passed urine and fæces under him. He resisted all attention and it was very difficult to feed him. He had a number of attacks in which there was conjugate deviation of the eyes to the right, with fixed stare and rigidity of the head for about two minutes.

A fortnight later he was in much the same condition, and his mother, who visited him, failed to attract his attention. Four weeks after he had been gassed, during his removal to the ambulance train en route to England, he became very noisy, quite incoherent, and showed signs of great mental perturbation. He was admitted into Netley Hospital as a case of acute delirium following CO poisoning.

The following is the report from Netley : " His expression is marked by lack of intelligence. His aspect and regard have those of extreme mental defect. His attention is readily obtained and is controlled by visual objects to a marked degree. There is agnosia with apraxia ; he reads readily, but inaccurately, and without much appreciation of meaning ; his responses are erratic and are marked by preservation, and at times by echolalia. He is disorientated ; his memory is markedly defective ; there are evidences of delusional formations. He is usually quiet and unagitated. He makes a pretence of occupation, but his performance is very poor ; he is unable to perform the simplest acts of toilet and requires complete supervision by his nurse. No evidences of sensory disturbances have been observed."

Five months later found him slowly improving. " His consciousness is natural ; there is no agnosia ; he converses intelligently, is correctly orientated, and realizes his own illness and the progress which he has made. There are still defects of memory and his mental performance is still imperfect." At the end of six months he had made considerable progress, but he still had bad days when his memory was very poor. He was at home. His mother reported that he had forgotten many little things. " For instance, he has a pair of Oxford shoes, but he told me he could not wear them as he could not tie a bow ; but he manages now all right after once being shown how." A few months later he was passed fit for active service, and he returned to the tunnelling service in France. It was found, however, that his memory was not reliable, and he could not be trusted with any important work.

Loss of memory was one of the most prominent of the mental disturbances which followed CO poisoning in mines. It came on rapidly not slowly. The degree of mental confusion, which is so characteristic of CO poisoning, may have had a good deal to do with certain of the cases of defective memory, more especially those cases in which memory could be easily re-awakened.

All degrees of loss of memory were met with. It existed in a minor degree in many cases which recovered from the acute poisoning, and in which no other symptoms could be detected ; in these cases the general memory remained defective for a considerable time. In the hospital when these patients were able to go about, they lost their way, forgot the names of their attendants and comrades, when they were last fed, and so on, and after returning to their units N.C.Os. and men forgot their orders and duties, and officers, for the same reason, could not be trusted with certain work. Names, time, and all details were readily forgotten ; indeed, loss of memory with disorientation in regard to time and space must be regarded as characteristic of CO poisoning.

Total loss of memory for some definite period of time was often seen, for example, a brief period of time before the gassing and the events which happened immediately after being completely erased from the mind. Memory for events which happened years ago was generally good ; usually it was memory for recent events which was the first to go, although in rare cases the whole previous life of the patient was blotted from memory.

Paramnesia was occasionally met with in the cases of multiple neuritis.

Where loss of memory was marked, it was generally accompanied by a certain degree of mental weakness, and where it lasted for a long time permanent mental weakness developed. In most cases memory was slowly regained after a certain stage had been reached ; in a few cases recovery took place suddenly.

Prognosis.

The great majority of the cases of CO poisoning, if rescued from the mines alive and promptly treated, recovered. If a patient did not quickly recover consciousness on the exhibition of oxygen the case was regarded as serious, for even if the man recovered temporarily after-effects were more liable to occur. The deeper the coma the more profound was the effect of CO on the nervous system. A very slow pulse or a very rapid and hardly perceptible pulse were both grave signs. In a number of cases where Cheyne-Stokes breathing occurred death resulted. Cases were reported in which recovery had apparently taken place, when suddenly, without the development of any grave symptom, death occurred. Men frequently died on their way to the dressing station after they were thought to be out of danger. In connection with this, the peculiar action of CO on the vital centres must not be forgotten. Where exposure to CO has been prolonged, serious relapses and sudden death were more liable to occur than where exposure, even to a very high percentage of CO, was of short duration, because the vital centres in the brain cannot stand prolonged deprivation of oxygen. Generally speaking, in serious cases of CO poisoning if death did not take place within twenty-four hours recovery almost invariably followed.

Morbid Anatomy.

Attention has already been drawn to the changes in the skin which are sometimes encountered. Where exposure has been prolonged and saturation of the blood by CO pronounced, the skin in the region of the chest, face, insides of thighs, and over the forearms and shoulders, may exhibit a bright red colour, and on section the muscles may show the same bright colouring.

The lungs and liver may have a pinkish or rose-red appearance. The blood, more especially if there has been a considerable degree of saturation with CO, is generally of a bright cherry-red colour. But these colour changes in the blood and parenchymatous organs will not be seen where the patient has lived for some time after being taken out of the mine, as a considerable proportion of CO—the amount depending upon the length of exposure in good air—will have been freed from combination with the hæmoglobin.

In those cases where rapid death has occurred, the *post-mortem* changes are those of asphyxia. The venous system and chambers of the right side of the heart are engorged with blood, as are also the parenchymatous organs.

In typical cases of CO poisoning the pathological findings are very similar to those found in various toxæmic conditions. Areas of intense hyperæmia may be seen in the pia mater, parts of the brain, lungs, etc. Minute punctiform hæmorrhages are frequently found in the brain, which in some places coalesce into larger areas ; these hæmorrhages are very characteristic of CO poisoning.

A *post-mortem* examination was carried out on a man who was found in a deeply comatose condition in a mine. When admitted to a casualty clearing station he was in a semi-unconscious condition, unable to speak, but able to swallow. There was incontinence of urine and fæces, twitchings of the face, and general spasms, which gradually increased till death occurred three days after the accident. *Post-mortem* examination showed great engorgement of the vessels of the brain and meninges, capillary hæmorrhages in the white matter, but no gross lesions ; the other organs were normal except for early signs of parenchymatous nephritis in the kidneys.

In the cortex the blood-vessels may be found congested and dilated, and many of the capillaries thrombosed. Examination of these may show rupture frequently limited to the perivascular sheath which may sometimes pass into the brain substance. Various stages of degeneration of the endothelium of the vessels may be found. The same changes may be found in the vessels of the basal ganglia, of the pons Varolii, and of the medulla oblongata. Multiple punctate hæmorrhages are especially common in the centrum ovale, internal and external capsules, optic thalamus, and cortex, and may be accompanied by chromatolytic and atrophic changes in the ganglion cells in proximity to the hæmorrhages and, if the patient has lived long enough and the changes have been progressive, areas of necrosis. Microscopic sections show the disappearance of nerve cells in these areas. The anatomical relation of the cerebral vessels favours the development of the hæmorrhages which are so frequently seen in CO poisoning.

Lieut.-Colonel Gordon Holmes found, in a most interesting case of CO poisoning which survived eleven days, that few cells in any portion of the cortex stained normally ; even at some distance from the areas of softening many were shrunken and stained deeply and homogeneously, while no Nissl bodies could be recognized in most of the others. The cortical softenings did not involve the white matter to any appreciable extent. In sections of the lenticular nuclei similar areas of softening, also limited to the grey matter, were found ; these were much more numerous and extensive than appeared probable to the naked eye. The softened areas were filled with tightly packed cells of neuroglial origin. The smaller vessels of these areas were also thrombosed but no hæmorrhages were seen.

Regarding the nature of the pathological process, Gordon Holmes thought that the primary change was thrombosis of the smaller vessels and capillaries of the grey matter; and the deeper layers of the cortex, which are supplied by a network of very fine vessels and the vitality of which is very dependent on a proper blood supply, are consequently the parts that have suffered most severely. This thrombosis may be to some extent dependent on, or at least favoured by, the intimal changes, though he was of opinion that its chief cause was a change in the constitution of the blood. This pathological condition has all the features of a toxic origin, though it might be simply the result of oxygen want. CO intoxication leads to the greater concentration of the blood which favours thrombosis.

In one *post-mortem* examination of CO poisoning Sir Frederick Mott found throughout the white matter of the centrum ovale, and especially in the corpus callosum, internal capsule and cerebral peduncles, multiple punctate hæmorrhages, which also occurred in the subcortical white matter and in the basal ganglia. Microscopic examination showed isolated capillary hæmorrhages in the grey matter ; in the medulla there were only congested vessels but no hæmorrhages. In the cells of the medulla a marked chromatolysis with swollen clear eccentric nucleus was shown. In the cortex many of the Betz cells showed a very marked chromatolysis, swelling of the cell and eccentric nucleus, while others in the immediate neighbourhood possessed a fairly normal amount of basophile Nissl granules. Besides these changes many of the small vessels exhibited inflammatory changes.

All the changes described above explain the variety of nervous disorders which follow CO poisoning, and why a small percentage of these is permanent.

Treatment.

The most important part of the treatment of CO poisoning was the immediate first aid treatment in the trenches carried out by the mine rescue men. The only possible way of getting good results from first aid is to have a rigid, stereotyped line of treatment. In the mine rescue schools it was insisted that all should have a thorough working knowledge of the administration of oxygen and of how to perform artificial respiration. Instructions regarding treatment were printed on cards and placed in every mine rescue station in the line, and were also put into all boxes containing oxygen reviving apparatus.

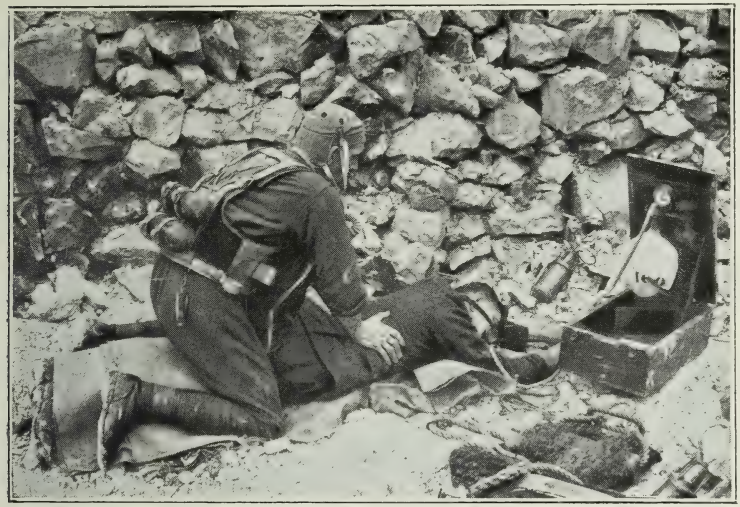

Fig. 1.—Artificial respiration (Schaefer's method) and administration of oxygen by mine rescue man in the trenches.

Schaefer's method of artificial respiration was the one fixed upon as the simplest, and it was the only method taught in the schools. Men practised this every day till they became expert. No case was ever heard of where damage was done to the patient by too vigorous movements, and artificial respiration must have been carried out many hundreds of times in the front line under the exciting and trying conditions met with at the time of a blow.

The use of the Novita oxygen reviving apparatus was also carefully taught and every day the men administered oxygen. It is no use showing the men the apparatus a few times and demonstrating its use. They must be allowed to use it, combined with artificial respiration, every day. This is the only way in which they will become expert in its use. The men were trained to carry Novita sets down the mine; during actual rescue operations reviving sets were taken below whenever possible, so that where a number of men were gassed and it was difficult to move them until further assistance arrived, oxygen could be administered. In desperate cases it was always administered before the man was removed in order to drive sufficient CO from the blood to permit of the removal being carried out with safety.

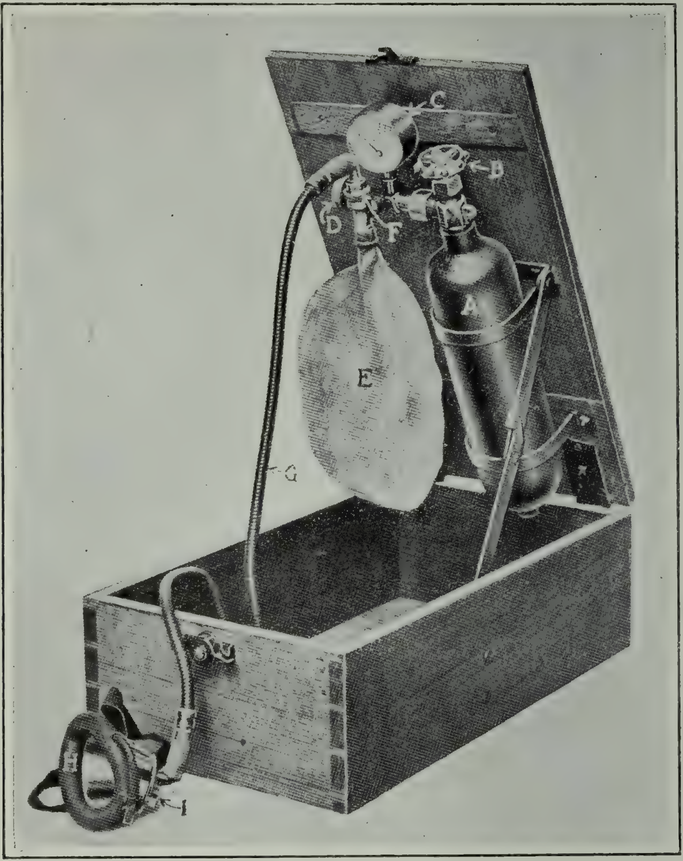

Fig. 2.—The Novita. A, oxygen cylinder, 6 cub. ft. capacity, fitted with a main valve B; C, a pressure gauge; D, a fine adjustment valve; E. a flexible bag; H, a mask.

The administration of oxygen is of the utmost value, as it drives out the CO from the blood five times more quickly than air. The method of administering oxygen through a nozzle held to the mouth or nose, which was done before oxygen reviving sets were obtained, is almost valueless, as most of the oxygen escapes into the atmosphere. In all cases where breathing has stopped, become shallow or very slow, the giving of oxygen should be combined with artificial respiration until the breathing becomes sufficiently deep to enable the blood to be cleared of CO. In all serious cases the men had strict orders to persist in the administration of oxygen. After natural breathing was restored the administration of oxygen was continued for some time. It was demonstrated that this had the effect of lessening the severity of the after-effects.

The wonderful effect that oxygen, combined with artificial respiration, has in reviving men who have been seriously—apparently even hopelessly—affected by CO poisoning and the necessity of persevering for a considerable time in efforts to resuscitate them, even though to all appearance life is extinct, was demonstrated in the following rescue work.

> After an intense bombardment the enemy raided our trenches and with a large mobile charge blew the entrance to the shaft leading to a tunnel in which thirty-six infantry were sheltering. Of these twenty-five lost their lives from the effects of the explosion and from CO poisoning before they could be rescued. Australian mine rescue men with apparatus from the rescue station were quickly on the scene, and succeeded in rescuing and resuscitating eleven men and in recovering the bodies of the others. The rescue work was most smoothly, rapidly, and efficiently carried out. All the men who were rescued were in an unconscious condition and seriously affected by CO poisoning. Two appeared to be lifeless, and a medical officer who was present thought it hopeless to persevere. The rescue men, however, having had instructions to do so in all such cases, persevered, and had the satisfaction, after ten hours' work, for a good part of which oxygen was administered, of saving both men. All the other men required oxygen and most of them artificial respiration.

Owing to the action of CO in reducing temperature the application of warmth is essential, and blankets and hot-water bottles were kept at all the rescue stations.

In the early days of mine warfare the value of rest in the treatment of mine gas poisoning was not appreciated ; indeed a common method of treatment, one which was formerly greatly in vogue in collieries and in ironworks, was walking the patient about after he had come to. This was frequently done in those cases where the patient got into a drowsy state. This method of treatment frequently resulted in the patient losing consciousness. A number of men who had been severely gassed, treated at the mine head by oxygen, and had partially recovered, died on their way to, or shortly after arrival at the dressing station. A peculiar feature of CO poisoning is that relapses are frequent, so that a man who has apparently recovered may develop serious symptoms and die. The too hasty removal, it does not matter how carefully this may be effected, of a man who has been seriously gassed may bring on a serious relapse. The following order was issued : " If possible, no man who has been gassed should be permitted to march back from the trenches to camp. Men who have been unconscious should, if possible, be kept in a dugout near the shaft head for at least two hours before being taken to the dressing station." It was proved that recovery was greatly hastened and serious after-effects avoided where this order was carried out.

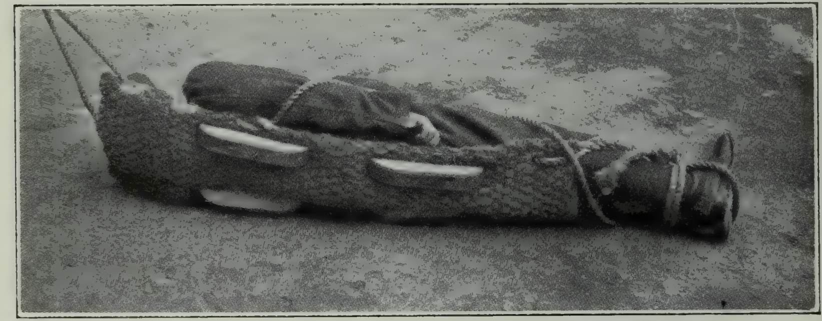

Fig. 3.—Mine stretcher, showing skids.

In mild cases hot strong coffee was administered, supplies of café-au-lait being kept at the rescue stations. Hypodermic injections of strychnine and pituitary extract were found of value in serious cases. In desperate cases transfusion of blood acted in a wonderful way.

A favourite line of treatment in the early days was the giving of emetics. The rescue men were warned against this on account of the possibility of inhalation pneumonia resulting. The exhibition of phenacetin, aspirin and such drugs for relief of the intolerable headache was forbidden owing to serious attacks of heart failure having followed their administration.

The following were the orders for the disposal of gas poisoning cases in the trenches. They were necessary on account of the serious wastage which took place at one time. Special labels for mine gas poisoning were provided ; these were attached by the mine rescue men under the supervision of the officer in charge.

" *In mild cases*, the labels with *Carbon Monoxide Gas Poisoning, Mild Case*, should be used. All such cases should be returned to billets, and placed in charge of the medical officer of the company. They should not be sent to the advanced dressing station. Should any find their way there they should be sent back to their unit. These men should be ready for duty in a few days.

" *Where the man has been rendered unconscious*, the red label should be used. These cases will be sent to the advanced dressing station and thence to the field ambulance in the ordinary way. All gas poisoning cases are now notified to and examined by the medical officer of the company to which they belong, who will advise as to their disposal. Unless some after-effect develops, most of these cases will be able to return to duty in the course of a week. When the immediate after-effects of the gassing disappear, which is usually in a few days, the men may be sent to a convalescent or rest camp, as little treatment other than rest and fresh air is required. "

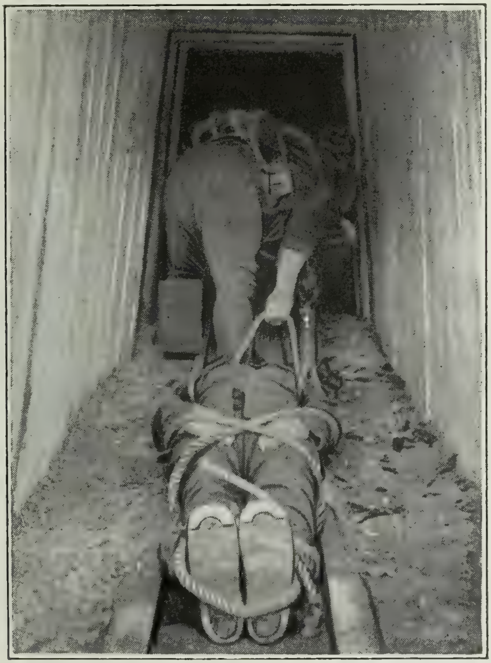

Fig. 4.—Showing use of mine stretcher in galleries.

In the early days of mining life-lines were used for hoisting men up the shaft. The difficulties and dangers of this method of bringing up an unconscious man—the constriction of the chest wall and the resulting serious effect in certain cases, the danger of the rope slipping, and also the great exertion entailed in hauling a man along the galleries—showed the necessity of obtaining a stretcher which would be useful in the gallery and in bringing men to the surface. In a few weeks a mine stretcher, designed by Lieutenant Penman, R.E., one of the officers in charge of mine rescue schools, was in use. From the accompanying photographs it will be seen how useful this stretcher was in dragging a man along the galleries with the least possible exertion for the rescue men, the skids on the bottom of the stretcher facilitating this. The rescue men were so expert in the use of it that a man could be securely fixed to it in a few seconds and hoisted to the top.

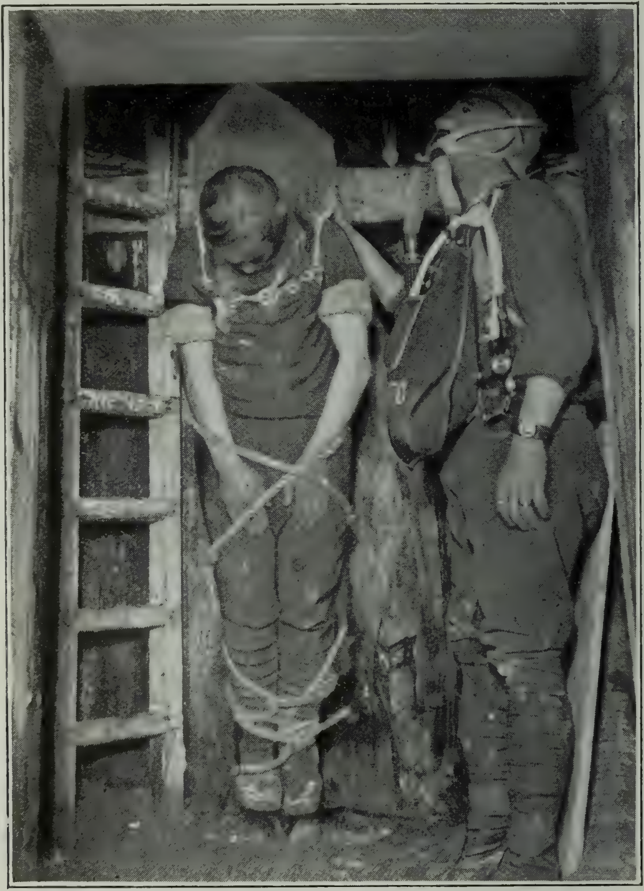

Fig. 5.—Patient on mine stretcher at shaft bottom before being hoisted.

CHAPTER XXI.

MINE RESCUE WORK.

THE Proto apparatus was adopted for general mine rescue work, as it was considered the simplest and most efficient rescue apparatus. (Figs. 1, 2, 3 and 4.)

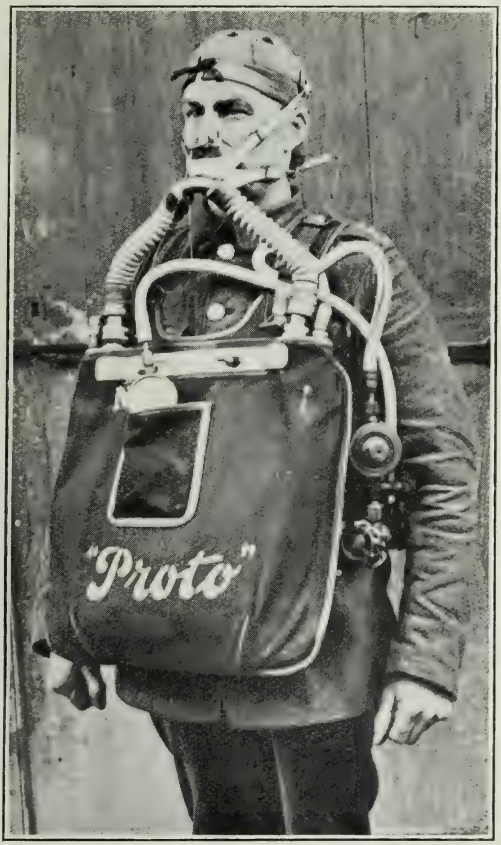

Fig. 1.—"Proto" mine rescue apparatus.

The twin cylinders of compressed oxygen (BB), containing 5 cub. ft. or 280 litres of oxygen under a pressure of 120 atmospheres, are slung over the back, fitting comfortably. (Fig. 4.)

These are fitted with a wheeled valve (H), the main valve, which is supplied with a device which makes it impossible to turn it off accidentally. A reducing valve (C) is screwed to the delivery nipple and can be adjusted to pass from 1½ to 3 litres of oxygen per minute. The reducing valve is provided with a by-pass which short-circuits it so that, should the reducing valve fail to act or should the wearer require a larger supply of oxygen than can be delivered by the reducing valve, as in very strenuous work, he can get a special supply direct from the cylinders.

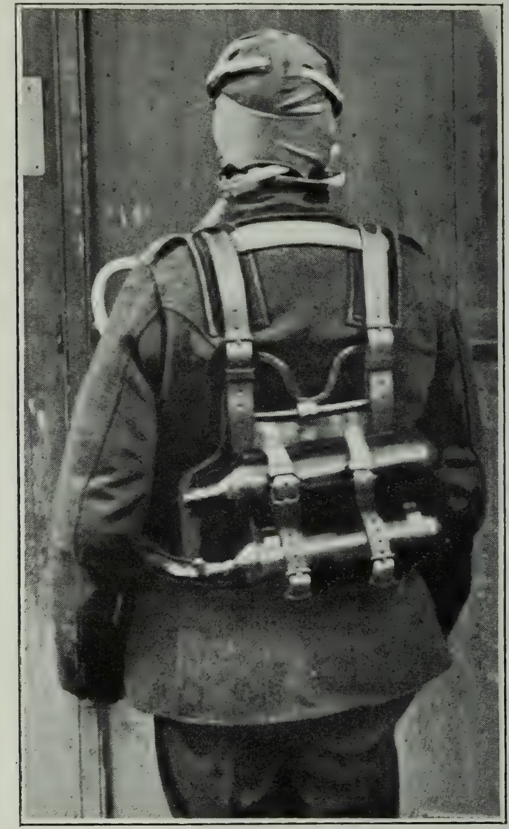

Fig. 2.—" Proto " mine rescue apparatus.

The reducing valve delivers the oxygen through a flexible tube (F) to the breathing bag (D), which is carried on the wearer's chest. Here it mixes with the air to be drawn into the lungs. There is another connection at (V), to which is connected a flexible high-pressure tube (W) at the opposite end of which is fitted a pressure gauge (P), which is carried in a pocket and ready for inspection. The breathing bag (D) is of vulcanized rubber contained in an outer bag of strong tanned canvas. It is divided into two compartments by a partition running from the top to within a short distance of the bottom. In this bag are placed the sticks of caustic soda. Light mica valves are placed at the junction of the tubes and the bag at (M) and (L), so that the wearer inhales from the bag on one side of the partition and exhales into the other side, where the air passes over the caustic soda and CO_2 is absorbed. A saliva trap (Z) is fitted under the exhaling tube; it prevents the

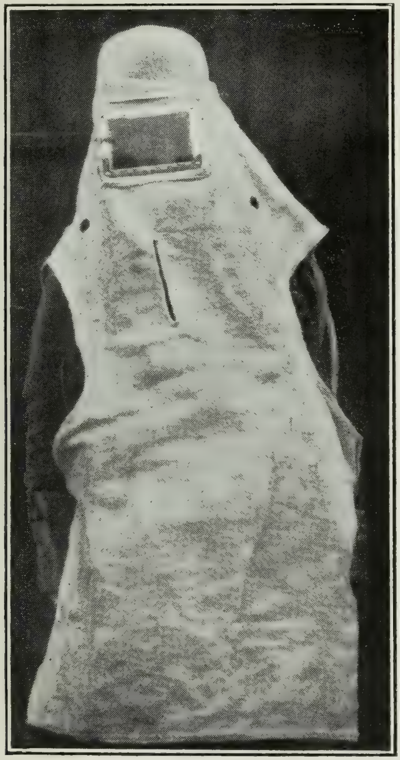

Fig. 3.—"Proto" mine rescue apparatus with asbestos hood and apron for use in fires in dugouts.

saliva from entering the breathing bag. (K) is a relief valve for the relief of any excess pressure in the bag. The mouthpiece is of soft vulcanized rubber fitted to a German-silver connecting piece (R). To the connecting piece are fitted strong corrugated tubes (X), which connect the mouth-piece with the upper corners of the bag. A nose clip compresses the nostrils.

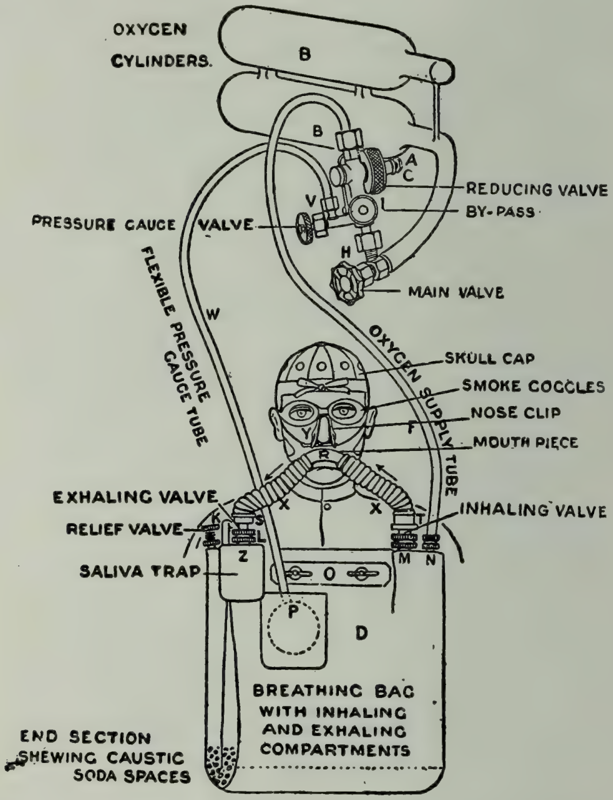

Fig. 4.—Diagrammatic view of the "Proto" rescue apparatus.

The Salvus Apparatus.—For scouting and work which did not necessitate more than half an hour in the mine, the Salvus apparatus was used. It was also used fitted to the mask of a box respirator, when lachrymatory gas was present. Generally speaking, for the purpose for which it was intended, namely, reconnaissance not entailing a long stay in the mine or arduous work, the Salvus gave excellent results. In all-round efficiency, however, it cannot be compared with the Proto.

Oxygen Resuscitating Apparatus.—In deciding on an oxygen resuscitating apparatus, it was necessary to remember the class of men who were to carry out first aid ; it was imperative that it should be of the simplest type and fool-proof. Automatic resuscitating apparatus, the best known of which is the Pulmotor, was rejected as being too heavy and complicated for use in the trenches, besides being dangerous in the hands even of medical men. The Novita apparatus was fixed upon and modified to meet the conditions of military mining, being coupled up in a box ready for immediate use (Figs. 1 and 2 of previous chapter). The box and handles were arranged in such a way that it was easily carried down the shaft.

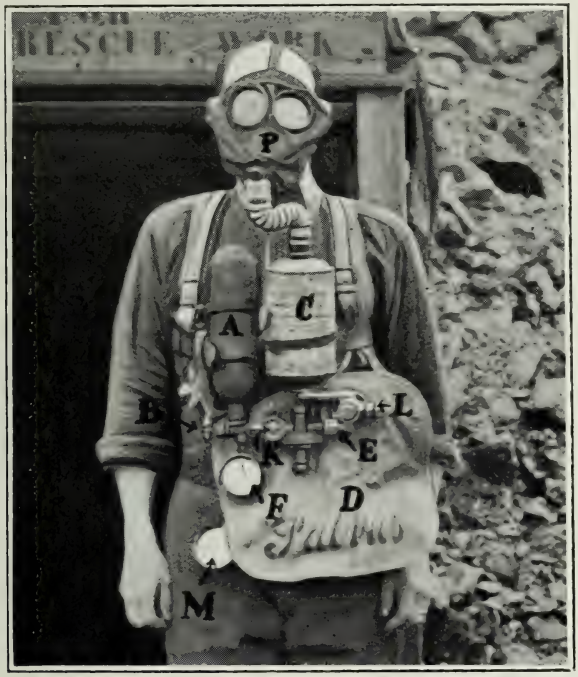

Fig. 5.—Description of "Salvus" apparatus. A, steel cylinder containing about three cubic feet of oxygen ; B, main valve ; C, CO_2 absorbent cartridge ; D, breathing bag ; E, reducing valve ; F, pressure gauge ; K, by-pass ; L, relief valve ; M, mirror ; P, mask of box respirator.

Mine Rescue Organization.—Mine rescue schools for the training of rescue men were started in each army. The officers in charge of these had skilled knowledge of rescue apparatus and of rescue work in coal mines, and in addition they had the great advantage of having been previously engaged in actual mining in the trenches; they therefore knew and appreciated the conditions under which the apparatus was used. Each was responsible for the general management of the school, supervision of training, and the control and distribution of all rescue apparatus in his army. One of his most important duties was to inspect from time to time the rescue organization of each tunnelling company, and submit any recommendations he had to make to the commanding officer who was responsible for the arrangements for mine rescue in his sector of the line being adequate and efficient, and also for the organization being kept efficient by weekly practices.

The course of training in the schools lasted ten days and consisted of lectures and demonstrations given by the officer commanding, the practical training being carried out by the instructors under the supervision of the officer. The "Memorandum on Gas Poisoning in Mines" (Official) was used as a manual. Particular attention was directed to the orders for mine rescue work in mines, which every pupil had to know thoroughly. The value of strict obedience to orders and the penalties of disobedience and non-observance of orders were insisted on.

In a course of training in rescue work everything depends upon the amount of practical work carried out, as only in this way can one become familiar with the apparatus. Not only must the men be accustomed to wear the apparatus, but they must have a thorough knowledge of every part of the apparatus and its uses, must know how to take the apparatus to pieces and re-assemble it, and how to remedy small defects. A thorough knowledge of the apparatus produces confidence as the wearer feels that, should anything go wrong with the apparatus, he has the requisite knowledge to remedy it.

Practice in wearing Apparatus.—The pulse-rate of each pupil was taken before and after each practice and entered in a book specially printed for the purpose. A record of the work performed and of the general condition of each man after practice was also kept. These records proved of the greatest assistance in the elimination of unsuitable men.

It was insisted that this part of the training should be very searching in character, approximating as nearly as possible to the work rescue men were called to do in the trenches.

The training in the schools included working at the face, driving and timbering galleries, recovery and disposal of the spoil, tamping and untamping galleries, building stoppings, walking quickly, climbing vertical ladders (a splendid test), walking up an incline, and recovering a good solid substantial dummy from under debris, placing it on a mine stretcher, dragging it along the gallery and bringing it to the surface, and so on. The value of tests involving considerable physical exertion, with its large oxygen consumption, was demonstrated. All the later tests were carried out in an irrespirable atmosphere. It was only by strenuous training that the men gained the necessary confidence in the apparatus, which is all-important in rescue work and which permitted them to face the most dangerous and trying conditions.

Company Mine Rescue Organization.—An officer in each company, the Proto officer, superintended the rescue organization and saw that all apparatus and material were kept in thorough order and in constant readiness, and that this was distributed according to the scheme drawn up by the officer in charge of the school. He supervised the weekly practices of the company rescue men and gave instruction in rescue work, in which he was assisted by the medical officer. If available, he personally supervised all rescue operations.

In each company a non-commissioned officer, who had attended the special instructors' course of training in the school, was appointed as instructor. His duties were to examine and test twice weekly all rescue apparatus in reserve and mine rescue stations, re-charging apparatus when necessary and returning at once all defective stock to the school. It was also his duty to take part in rescue operations when these occurred, and many of the instructors did splendid work in this way.

The following orders taken from the " Memorandum on Gas Poisoning in Mines " will give some idea of rescue organization in the trenches and of the measures which were adopted to prevent casualties. From time to time special steps were taken to impress on all ranks the importance of these orders and the necessity for implicit obedience.

"PREVENTION OF GAS POISONING AND ACCIDENTS IN MINES. GENERAL INSTRUCTIONS.

" I.—*After a Mine Explosion.*

" 1. *When a blow occurs, even though this appears to be a long way off, all men working below must come up at once.*

" 2. The officer in charge must be notified at once, and information sent to the nearest Rescue Station for the trained rescue men and apparatus. Where possible all the rescue apparatus and material should be carried by fatigue men in order that the rescue men may arrive at the mine perfectly fresh.

" 3. Whenever a blow occurs all the trained mine rescue men are to proceed to the nearest Rescue Station.

" 4. The officer in charge is to superintend rescue operations and is responsible that all orders are obeyed. He should see that everything is done to improve the ventilation.

" 5. *No man is to descend the shaft without rescue apparatus till the mine is reported clear of gas.*

" 6. A sentry must be posted at once at the shaft-head to carry out that order.

" 7. Men who have had no previous training in the use of rescue apparatus are forbidden to use it.

" 8. *Infantry are prohibited from taking part in rescue operations.* Where this order has been disobeyed, the would-be rescuers have frequently been seriously affected and absorbed the attention of the trained rescue party to the prejudice of the men in the mine, and valuable time and lives thus lost.

" 9. Rescue men should always work in pairs, never singly, unless under very exceptional circumstances.

" 10. *No naked lights are to be used in the mine till it is clear of gas.* Electric lights only are to be used, as the gas in the mine may be present in explosive amount. When men are in a mine when a blow occurs and their lights are extinguished, they should make their way out without re-lighting these; and where the force of the blow has not been sufficient to put out the candles, they must be immediately extinguished. A sufficient supply of miners' electric lamps should be brought to the mine from the Rescue Station, as work is more rapidly carried out in a well-lighted shaft and gallery.

" 11. The life-line (which is to be used for no other purpose than rescue work) at the shaft-head should be unwound ready for immediate use, and spare lines brought from the Rescue Station and kept in readiness.

" 12. A strong canvas belt with a hook should be kept with the life ropes at the shaft-head for use where mine stretchers are unavailable or cannot be used.

" 13. Mine stretchers should be sent down the mine. *No man who has been gassed is to ascend the shaft without being roped.* Serious cases are to be brought up on the mine stretcher.

" 14. Great care must be taken with all men, however slightly gassed, when they reach the shaft-head, as exposure to cold often leads to loss of consciousness.

" 15. *Before any apparatus is worn it must be carefully examined by the man who is actually going to wear it, special attention being paid to the valves and gauge.* Cases have frequently occurred where men have had to leave rescue work owing to some small defect in the apparatus, which should have been adjusted before descending the mine. A spanner and spare nose clips should always be carried in the pockets. When a number of men are involved in a blow, a relief squad with apparatus ready should be in readiness to assist at a moment's notice. Whenever any defect is discovered, punctured bag, leaking valve, diminished supply of oxygen, over-heating of caustic cartridge, owing to exhaustion of caustic soda, etc., the squad should immediately come out of the mine.

" 16. Blankets, trench stretchers, hot water bottles and café-au-lait must be brought from the Mine Rescue Station and kept in readiness.

" 17. Oxygen reviving apparatus (Novita) is to be taken into the mine by the rescue men whenever possible. Where there are a number of men poisoned and it is difficult to move them until further assistance arrives, oxygen may be administered; and in desperate cases it should always be given, as it will drive sufficient CO from the blood to permit the removal of the men with safety.

" 18. If any difficulty is experienced in getting down the small and medium circular steel shafts while wearing apparatus, a straight-down emergency ladderway in the hoisting compartment should be at once installed.

" 19. In very cold weather it is found that the caustic soda does not absorb CO_2 with sufficient rapidity for the first few minutes the apparatus is worn, with the result that difficulty in breathing is experienced. This difficulty is readily overcome by wearing the apparatus for a few minutes without putting on the nose clip, when the warm breath will quickly raise the soda to the temperature necessary for efficient absorption of CO_2.

" 20. *Men should be warned that the gas helmet and box respirator issued to the armies for protection against hostile gas* (*chlorine, etc.*) *afford no protection against mine gas, as CO is not acted on by the chemicals in the helmet or box.*

" II.—*Precautions to be taken where gas is known to be present in the galleries in such small quantity that work can be carried out, and minor symptoms of gas poisoning, e.g., headache, etc., only develop after prolonged exposure.*

" 1. Canaries or mice must be kept constantly in the mine, and changed every two hours.

" 2. Should the canary or mouse show any signs of being affected, all the men must come up at once.

" 3. When it is urgently required to carry out work in a gallery where exposure causes headache, etc., to develop in two hours, work should be carried out in relays, the men working ten to fifteen minutes with thirty minutes out.

" 4. Two Proto and two Novita sets, ready for instant use, should be kept at a place convenient to the shaft head ; and two rescue men engaged in such surface work as will permit of them being in instant readiness should their services be required."

Canaries and mice are useful as detectors of carbon monoxide in the air of mines, because they absorb the poisonous gas so much more quickly than man owing to their rate of breathing and circulation being so much more rapid. The heart-beat in these small creatures is from 750 to 1,000 per minute. In an atmosphere containing a percentage of CO which would begin to affect a man in half an hour, a canary and mouse would be affected in two minutes.

Mice, if properly trained, are not so easily frightened as canaries, and some consider them easier to use as a test. Lieutenant Eagar, the officer commanding the Second Army Mine Rescue School, was an enthusiastic advocate of the use of mice. In the method adopted by him the necessity of carrying a cage was done away with, which gave the rescue men more freedom. The mice were thoroughly trained and accustomed to handling. They were carried in the pocket till wanted for testing, and were trained to climb over the hand, in this way inhaling a great deal more of the air to be tested. A mouse used in this way will indicate the presence of CO more quickly than a bird sitting motionless on a perch in a cage.

Small birds and mice do not seem to suffer after-effects from CO, and when placed in good air generally recover completely in a few minutes.

Certain cases occurred which appeared to throw doubt on the value of canaries and mice as detectors, but on investigation it was found that there had been some error in the way the detectors had been employed. In every case the canary must be taken right into the place to be examined and kept close to the observer. There is one curious point regarding the effect of CO which is not well known. If CO is present in very minute quantity, too small to have any serious action on men even on prolonged exposure, it is occasionally found that after doing hard work in this atmosphere for more than two and a half hours men may complain of slight headache, giddiness, or feeling of sickness, while the canary or mouse remains unaffected. In any atmosphere which may cause serious symptoms of poisoning the canary or mouse will give ample warning long before the gas has any effect on a man.

In connection with the use of canaries in mines, the following incident may be recorded. One of the canaries kept in a mine rescue station escaped from its cage and flew into the middle of "No Man's Land," where, alighting on a bush, it began to sing. Consternation was caused in the British lines, for the discovery of this bird by the enemy would indicate the presence of mining operations and would mean that the work of weeks would go for naught. The infantry in the trenches were immediately ordered to open fire on the canary, but it continued singing, heedless of the bullets which whistled round it. It was not until the trench mortars were called on to assist that a well-placed shell wiped out completely the bird, the bush, and the song.

Mine rescue stations (Figs. 6 and 8), in which rescue apparatus and material were stored, were organized in dugouts in close proximity to all mines. When convenient, one station served a group of mines, but when possible they were never placed more than 250 yards away from any mine shaft. Difficulty in getting along the fire trench, owing to the conditions of the trench, was taken into consideration when placing apparatus. In certain cases it was found necessary, owing to the dangerous character of the work and gassy condition of the mine and the condition of the trenches, to keep apparatus ready for immediate use at the shaft-head. When this was done, it was kept in the cupboards specially designed for the purpose. Two trained rescue men were on constant duty at these stations. These men had a thorough knowledge of the position of each mine served by their stations and were familiar with the various workings.

Besides apparatus, spares and refills, two asbestos hoods and aprons for use in underground fires were also kept. Rescue stores included the following: Blankets, Primus stove, hot-water bottles, café-au-lait, miners' electric lamps, trench stretchers, mine stretchers, life-lines, a saw, and an axe. At least three canaries and three mice were kept either in the station or in the officers' dugout.

Rescue Work in the Trenches.—In rescue work in the trenches the necessity of not wasting time in recovering the dead until all chance of saving others had gone was insisted on; it was also emphasized that, as the object of rescue work is not only to save life, but to prevent further accidents, obedience to standing orders must always be most carefully observed.

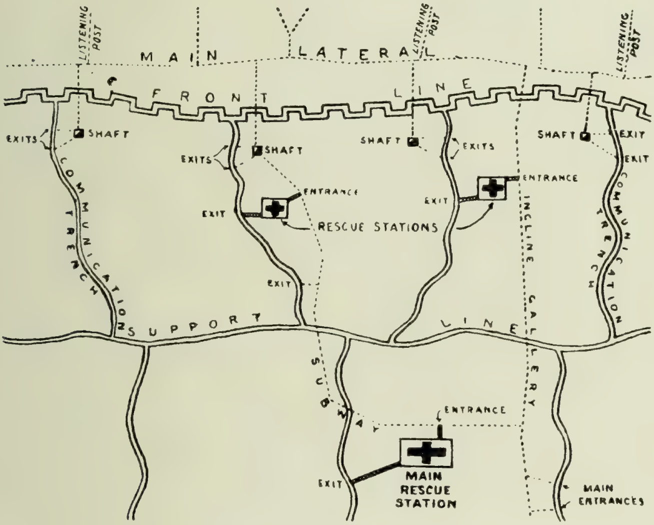
PLAN SHOWING RELATION OF MINE RESCUE STATIONS TO MINE SYSTEM

Fig. 6.

The following will serve as a good example of rescue work and of mine recovery work, such as removal of obstacles caused by the explosion, clearing of air pipes and the re-installation of ventilation, and the dispersal of gas from the galleries—a combination of rescue work and mining operations which was so frequently carried out along the whole front.

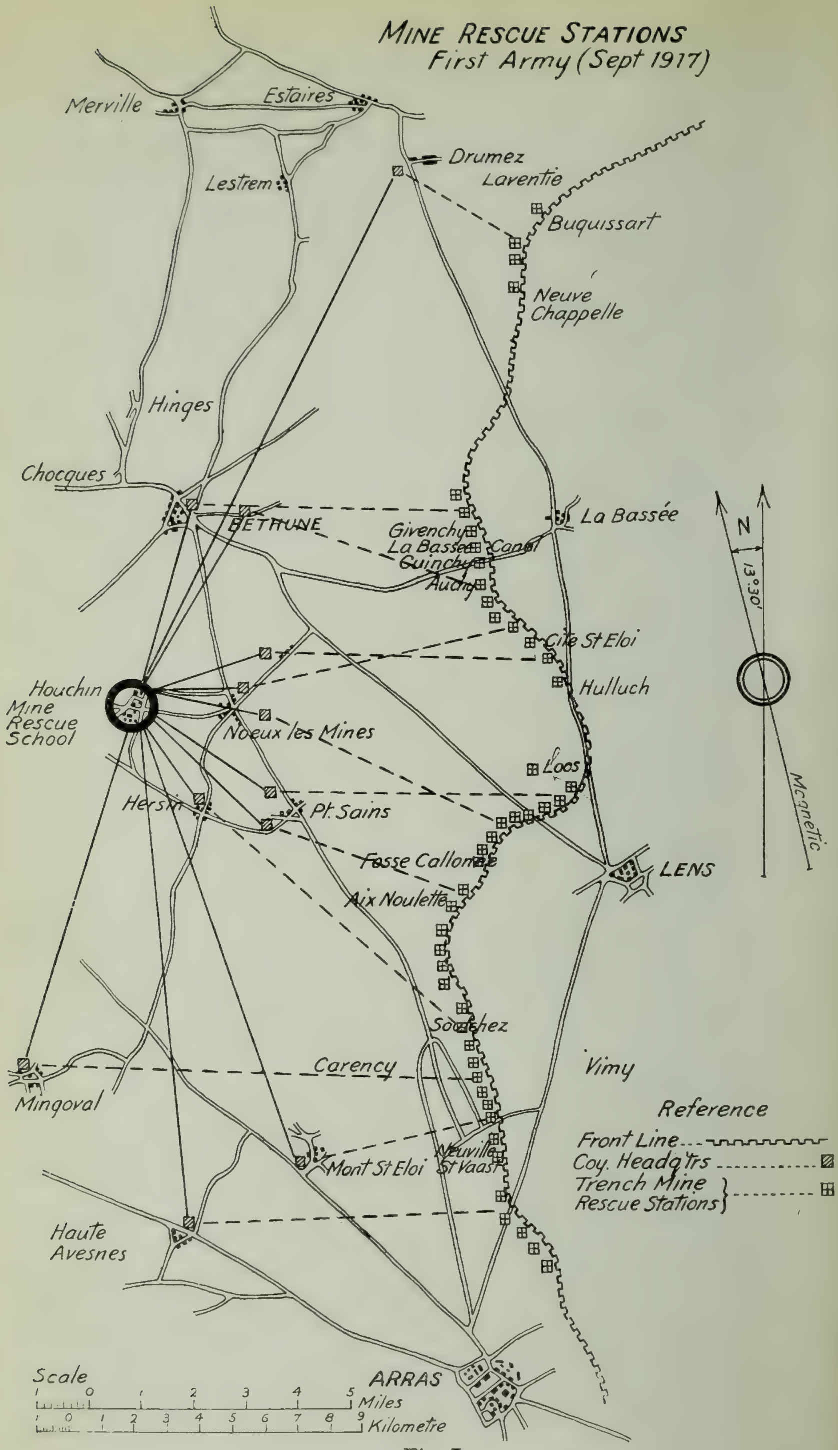
Mine Rescue Stations
First Army (Sept 1917)
Merville
Estaires
Drumez
Laventie
Lestrem
Buquissart
Neuve Chappelle
Hinges
Chocques
BETHUNE
La Bassée
N
13°30'
Magnetic
Givenchy
La Bassée Canal
Guinchy
Auchy
Cite St Eloi
Hulluch
Houchin Mine Rescue School
Noeux les Mines
Loos
Hersin
Pt. Sains
LENS
Fosse Callonne
Aix Noulette
Souchez
Vimy
Carency
Mingoval
Reference
Front Line
Coy. Headq'trs ▨
Trench Mine Rescue Stations ⊞
Mont St Eloi
Neuville St Vaast
Haute Avesnes
ARRAS
Scale
1 0 1 2 3 4 5 Miles
1 0 1 2 3 4 5 6 7 8 9 Kilometre

Fig. 7.

Six men were at work in a mine when the enemy blew a mine. Two men who were working at the face were killed. On hearing the sound of the explosion, the rescue men from the rescue station made their way along the trenches to the shaft, under the heavy shelling which at that time generally accompanied mine explosions, entered the mine a few minutes after getting the alarm, and rescued four men, all of whom were unconscious, one being wounded by a piece of flying timber. On being brought to the surface on the mine stretcher the gassed men were treated by two other rescue men, artificial respiration and the administration of oxygen being required by two of the men who were seriously gassed ; the other two quickly regained consciousness on exposure to the fresh air.

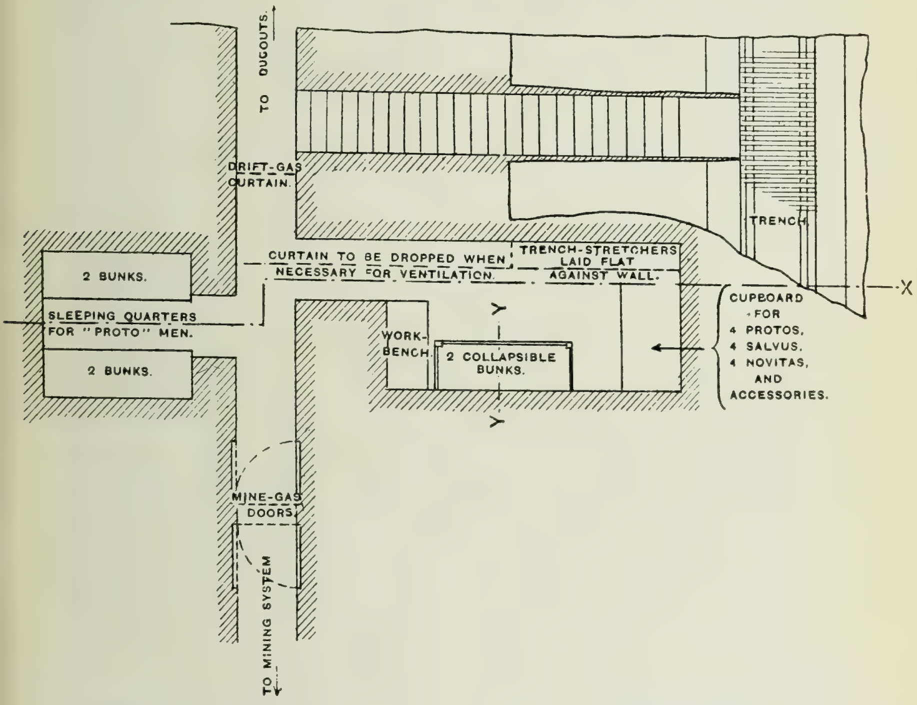
TO DUGOUTS.
DRIFT-GAS CURTAIN.
TRENCH
2 BUNKS.
SLEEPING QUARTERS FOR "PROTO" MEN.
2 BUNKS.
CURTAIN TO BE DROPPED WHEN NECESSARY FOR VENTILATION.
TRENCH-STRETCHERS LAID FLAT AGAINST WALL.
X
CUPBOARD FOR 4 PROTOS, 4 SALVUS, 4 NOVITAS, AND ACCESSORIES.
WORK-BENCH.
2 COLLAPSIBLE BUNKS.
MINE-GAS DOORS.
TO MINING SYSTEM

Fig. 8.—Plan showing general arrangement of Second Army trench mines rescue station.

After waiting for a quarter of an hour, the same Proto men who had rescued these men descended the mine to discover the amount of damage done and to find out whether the mine was clearing of gas. A mouse which they carried with them died after they had penetrated a short way into the galleries. Having cleared obstacles from the galleries, they proceeded to install ventilation and made it possible to resume work that evening.

The following day gas again came through into the gallery, probably as the result of settling of the ground disturbed by the blow. Three men who were rendered unconscious were rescued and brought to the surface, where oxygen was administered and the men wrapped in blankets with hot-water bottles, and kept in the rescue station before being sent down to the aid post.

The following is an example of how prompt obedience to standing orders and orderly and efficient supervision of rescue work by the officer in charge prevented more casualties and permitted of work being carried out smoothly and rapidly.

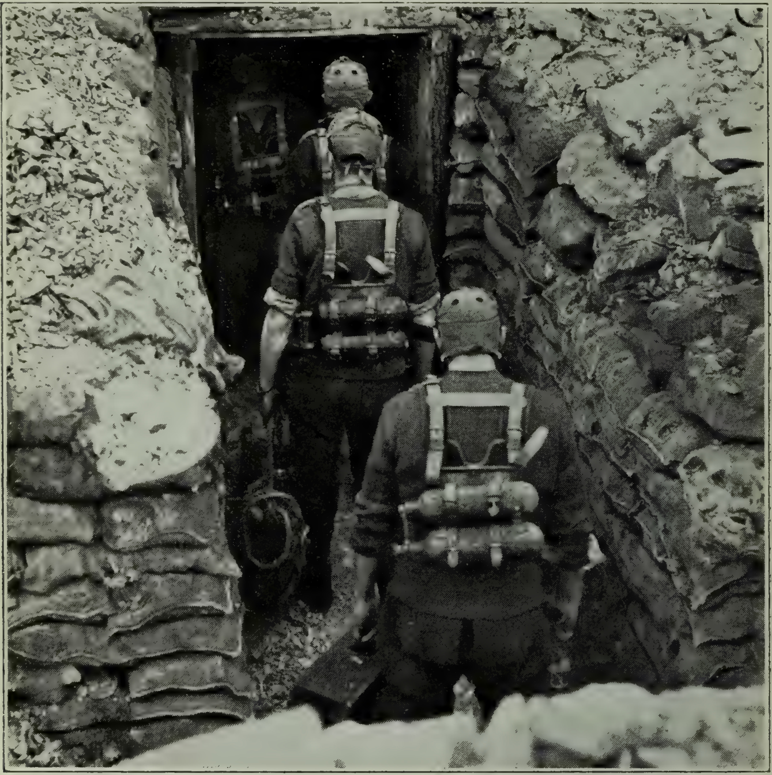

Fig. 9.—Mine rescue squad carrying mine stretcher, Novita oxygen reviving apparatus, and miners' electric lamps, entering mine after explosion.

Eight men were underground in one of our mine systems at the time of an enemy blow. Of these, two were working at the face near which the blow occurred. Immediately the men made their way out, after extinguishing their lights. One reported to the N.C.O. in charge that the man who was working with him at the face was partly buried by débris, and that in attempting to rescue him he felt himself being overcome by gas and thought it advisable to go back for help. The N.C.O. ordered all to the surface. The exertion of making his way out rendered the man who had been gassed unconscious. On hearing the blow, the officer in charge immediately ordered the mine rescue men to stand-to, and they arrived at the shaft-head ready to descend within a couple of minutes after the men emerged from the shaft. They descended the shaft and found the man half-covered with debris and unconscious. He was liberated, dragged to the bottom of the incline, placed on a trolley, and sent to the surface. Notwithstanding everything that was done (artificial respiration and administration of oxygen were persevered with for two hours), this man died.

Had the men who were down the mine remained to rescue their comrade, as was done so frequently in such cases in the early days of mining, instead of obeying standing orders and immediately coming to the surface, it is certain that more serious results would have occurred and that the rescue work would have been complicated and delayed.

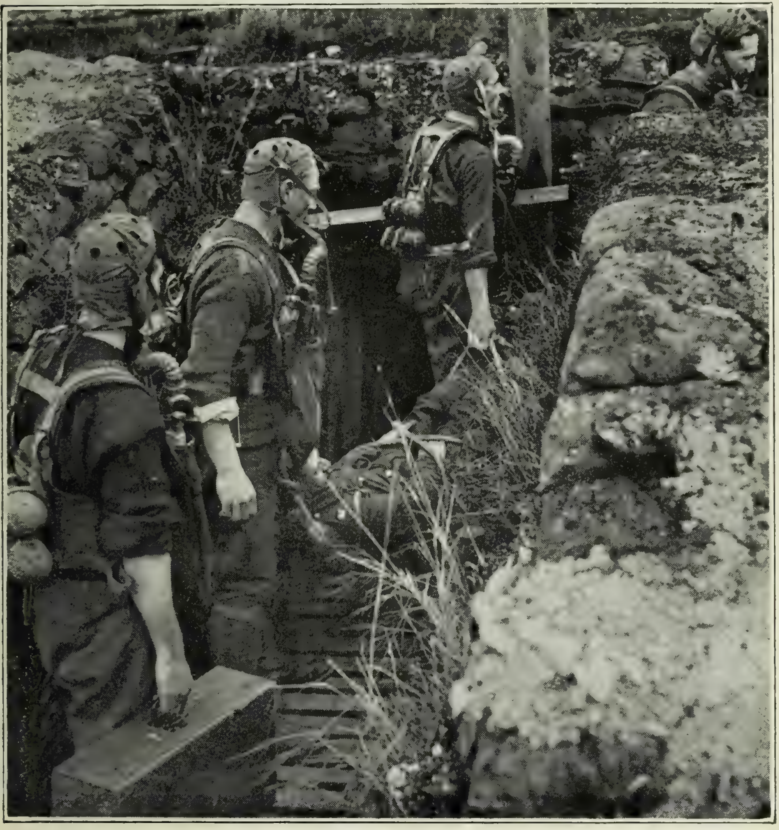

Fig. 10.—Mine rescue squad carrying gassed man on mine stretcher in the trenches.

It must be remembered that during the intensely active mining period mine explosions were frequently accompanied by fierce bombardment of the trenches, which added to the difficulties of rescue work. Not only so, but other difficulties, some of which were unavoidable and others the result of trench warfare, made rescue operations extremely hazardous. The following four incidents are examples of these difficulties.

(1) During an enemy bombardment a heavy minenwerfer bomb or shell pierced an officers' dugout quarters and exploded, killing three officers. Five other officers were more or less seriously gassed. Proto men from the rescue station, who had to pass through heavy shelling, were quickly on the scene and succeeded in rescuing and resuscitating these officers.

Further investigation showed that the explosion had almost closed the bâtmen's quarters, communication being only possible through an opening which was just sufficiently large to allow a Proto man through. This part of the system was heavily charged with CO. A Proto man immediately entered and inspected the place and found six men, all of whom appeared to be dead. Part of the roof was destroyed and the ground overhead, being running sand, made the place very dangerous, particularly in the vicinity of the entrance. When coming out to report, the Proto man got into difficulties on account of his feet and apparatus getting entangled in electric wire, and it was with great difficulty that he was dragged to safety.

Another Proto man entered to make a further inspection, but when near the entrance, was buried by a fall of earth. The officer who was directing operations at once freed the head and shoulders of this man and applied the mask of a Novita oxygen reviving apparatus to his face. "He was breathing for a period of nearly two hours in this position, the mask being kept applied constantly, the cylinders of oxygen being quickly changed when fresh ones were required. Time after time we got the earth off his head and shoulders, but another fall would bury him again. On some occasions he was completely buried for a period of over a minute, but breathing was resumed with the administration of oxygen. There was room only for one Proto man to work at a time, and each was constantly relieved." A heavy fall at last occurred which completely buried him and partly buried the Proto man, who was dragged out. When his body was recovered, it was found that his feet had become entangled in electric wire, and that wire had caught round his waist.

(2) After an enemy blow two men who were in the mine at the time were caught by the broken timber, and they could be heard talking by the rescuers, from whom they were separated by about 30 ft. of wrecked timber. After working for eight hours the rescue party was able to extricate both men alive.

In a neighbouring gallery in the same mine a listener was cut off. Rescue presented the greatest difficulties as the ground was running badly, threatening to cut off the rescue party. When the man was reached, he was found to be badly squeezed, and it was necessary to work round both sides of him before he was finally rescued, after being entombed for nearly ten hours.

(3) In another case, two men were cut off by a blow and separated by 70 ft. of wrecked gallery from the rescue party. Fortunately, the two armoured air-hoses were not quite flattened, and this not only prevented the men from being asphyxiated, but permitted of communication being kept up with them. The rescuers worked in double parties, one pushing ahead as fast as possible and the other following up the work with temporary sets and struts to make the gallery safe. Work was still in progress twelve hours later when the enemy blew a camouflet against another part of the mine. The workings had to be cleared to test for gas, which, however, was found to be absent. Work was resumed after being suspended for an hour, and five hours afterwards the men were released.

The difficulties in the trenches were sometimes so formidable as to embarrass and delay rescue operations very seriously. The following is an example :—

(4) A few days after the French part of the line at Arras was taken over by the British the enemy sprang a mine. In this part of the line shelling had been so continuous and the damage to the trenches so serious, that it was held only in sufficient strength to protect the mine system.

The trenches were very deep and narrow, overlooked by the enemy, and in bad repair. On the morning of the blow they were so badly damaged by heavy shells as to be almost impassable ; 12 ft. to the left of the shaft the parapet had been completely destroyed the night before.

The very small dimensions of the old French incline rendered all work with Proto apparatus extremely difficult, the great exertion entailed exhausting the men very quickly. The galleries were very low and narrow (3 ft. by 3 ft.), and the head-room was further diminished by a 6-in. air pipe that was attached to the roof. As the cylinders of a Proto apparatus protrude 3 in. from the wearer's back, the difficulty of passing down this gallery will be understood.

Immediately following the explosion of the mine there was a very violent inrush of gas which not only flooded the mine, but passed up the shaft and flowed along the trenches, where it rendered unconscious a number of infantry-men, and a mine rescue man who was coming along the trench from the mine rescue station was also overcome before he could apply the mouthpiece and nose-clips of the apparatus he was wearing, the custom being to apply these when the men reached the shaft. The experience of gas flowing along the trenches was unusual, and was explained by the narrow deep character of the trench, and by the atmospheric condition, which did not favour rapid dispersal of the gas. As the trench was so congested, it was necessary to clear it before rescue operations in the mine could proceed ; the men who had been overcome were treated with oxygen and removed.

In the circumstances it is not to be wondered at that rescue operations in the mine were considerably delayed. Fortunately trench conditions such as were encountered on this occasion were seldom seen, the galleries of the British mines and all the approaches being very much larger.

Rescue Work at Fires in Mines and Dugouts.—There is no more dangerous and terrifying accident than a fire underground. It is not difficult to realize that in such confined places where the galleries are comparatively narrow, the slightest confusion may lead to the most serious consequences. Owing to the way in which mines and dugouts are ventilated, with upcast and downcast shafts or inclines, the fumes are quickly carried through the workings, and gas poisoning may quickly occur at points at a considerable distance from the fire. The dangerous factor in all underground fires is CO, which caused more than 86 per cent. of the deaths. In the event of a fire breaking out in a dugout, men are very apt to become confused and their sense of location to be blurred in the presence of dense smoke, and instead of making for safety they may approach nearer the danger zone.

The mine rescue men were frequently called upon to deal with fires in dugouts, and their work proved of the greatest value, saving a considerable number of lives and much valuable material. They were ready at all times and never failed to answer calls for help from the infantry, and one can hardly picture more trying or hazardous work than that of extinguishing a fire in a dugout. The tunnellers were soon recognized as experts in this work, and in the great fires at Amiens and Béthune, which threatened to destroy these towns, it was the tunnellers who were called upon to deal with the situation ; this they successfully did.

In the rescue stations asbestos hoods and coverings for the Proto apparatus, so as to give protection against heat, were stored.

Fires in mines were not frequently seen. The following is a description of a most unusual one :—

> After the firing of an enemy camouflet, which must have been very imperfectly detonated as very large quantities of gas were formed, three gas explosions, at intervals of about three minutes, occurred. As a result, two fires started in the galleries. When the gas from the camouflet reached these points it was ignited and helped to feed the flames, long tongues of which darted along the roof of the galleries. A considerable number of men were in the mine at the time. They all managed to make their escape except four, who were killed by CO. The fire was extinguished very quickly by the mine rescue men working in Proto apparatus, and all the bodies were quickly recovered.

Fires in dugouts were much more frequently met with. The most serious underground fire in the British lines which occurred during the war was one which broke out in the bâtmen's quarters of a very extensive dugout system :—

> The fire was caused by some of the men using petrol instead of paraffin in a Primus stove. The stove exploded and set fire to the timber, and another tin of petrol alongside must have exploded almost immediately after, causing the fire to spread rapidly. The occupants of all dugouts, many of whom were asleep, were at once roused. A tunnelling officer took charge of the rescue operations. He, with three rescue men, went at once to the mine rescue station, where they obtained rescue apparatus. Probably, on account of the men being hurriedly awakened from their sleep, considerable confusion existed, and out of thirty-five occupants eleven failed to effect their escape and were asphyxiated. The officer in charge ordered the rescue men to start putting in tamping, and, wearing a Salvus set, he went forward to " E " stairs. Opposite " X " dugout he found a number of men struggling and was knocked down, but managed to get out. Various attempts were made by the rescue party to reach the men, but owing to the heat, they could only reach " X " dugout. Two of them attempted to tamp the entrance to gallery opposite " Y " but were beaten back by the heat. The two entrances from " E " gallery were then tamped up ; this cut off the supply of air to the fire. Further attempts to reach the men were rendered impossible by the heat. " E " stairs which had been tamped off were now opened up and men wearing apparatus succeeded in tamping up the entrance to the gallery opposite " Y " dugout, using the tamping at " E " gallery for the purpose. One of the Proto men then explored the gallery and dugouts to " E " stairs.

He found ten bodies between "Q" dugout and the lower section of "E" stairs. All attempts at resuscitation failed. In all, three lives were saved by the rescue men.

The next day, in another system of dugouts, a fire broke out as the result of petrol being taken from petrol tins which were supposed to contain water. To prevent further accidents and loss of material, the orders given below were immediately circulated. Mine rescue stations were also provided with asbestos hoods and coverings for the apparatus to protect it against the heat which had so seriously hampered rescue work in the fire described above. Steps were also taken to discover methods of treating dugouts which would render them incombustible, and the following instructions were issued :—

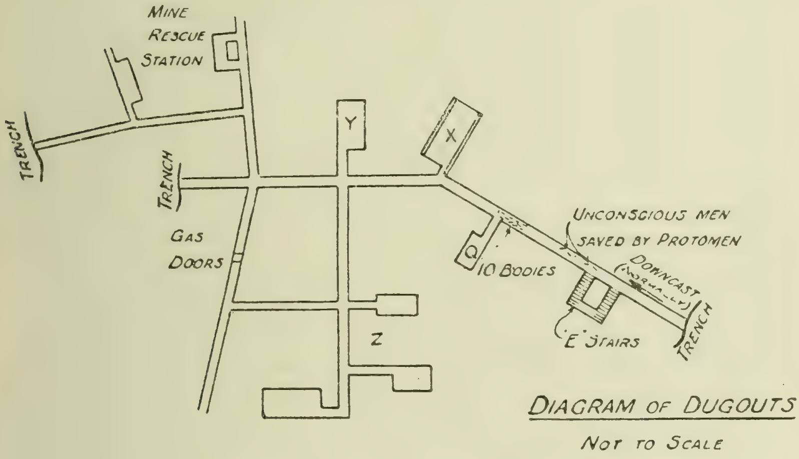

Fig. 11.—Disastrous fire in dugout.

"(1) Underground cookhouses will be provided with a door covered with tin, and a number of filled sandbags will be kept in a suitable position, so that, when a fire breaks out, the doors can be shut and a barricade of sandbags rapidly constructed to isolate the fire. Buckets of sand will be kept near each cookhouse to extinguish small fires.

"(2) When a fire breaks out underground, the officer, N.C.O., or man responsible for giving warning will clear everyone at once out of the whole system, sending the men out in one direction, if possible away from the fire. As the fumes are poisonous and far-reaching in their effects, the entrances and trenches in the vicinity must also be kept clear of men.

"(3) All tins containing petrol will be clearly marked PETROL.*

"(4) In extensive dugout systems, isolation doors, with handy stores of sandbags on each side of them, will be constructed at suitable points.

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* This was necessary on account of the fact that petrol tins were so largely used for carrying up water to the trenches.

"(5) If a mine rescue station is situated in the vicinity, a notice should be posted in all dugout systems showing its position. The men on duty at the station are available to render assistance in rescuing men and extinguishing the fire.

"(6) Security is best assured by holding frequent fire drills."

Mine rescue men proved of the greatest value in rescue operations in dugouts and saved a considerable number of lives and much valuable material.

Mining Operations carried out by men wearing Proto Apparatus.—When rescue men became available, they were frequently used to lay armoured hose, in order to clear the mine of gas and restore ventilation immediately after an enemy blow. In this way valuable time was gained. Examples of the usefulness of rescue men recovering mines after the completion of rescue work have already been given. Four other examples may be given. The first is an example of an incident frequently met with ; the second was the biggest military mining operation ever attempted by men wearing apparatus ; the third was another excellent example of charging and tamping a mine ; while the fourth enabled a very important mine to be blown at the battle of Messines.

(1) Two men were caught in a gallery that had been wrecked by an enemy blow. The work of clearing the gallery was carried out immediately by mine rescue men wearing Proto apparatus, who worked in pairs in thirty-minute shifts. On account of the damage done to the gallery and the small size (2 ft. 3 in. wide), work was slow, as only one man could work at a time, the other standing by in case of emergency and acting as relief.

While this work was being carried out, the air was tested with canaries and mice from time to time. About an hour after the blow, it was found that the air had cleared, but the men continued working in apparatus, fortunately, as shortly afterwards there was an inrush of gas, and a canary exposed to this was immediately killed. Air-pumps were rigged up, and air-pipes led in to clear the galleries of gas. Work was carried on for six hours.

(2) Owing to repeated blows, the ground in an important mining sector had become saturated with gas, and in attempting to work in this area a considerable number of men had been gassed. The enemy had approached underground within striking distance of our trenches, and it was absolutely essential for the safety of the line that the enemy should be held. Gas had been entering the galleries continuously from an enemy mine fired two weeks previously, and could not be sufficiently overcome by pumps to render ordinary charging operations practicable. In a sample of the air which was taken, 1·65 per cent. of CO and 16·77 per cent. of oxygen were found, an atmosphere which would prove rapidly fatal to any exposed to it. Work being at a standstill it was resolved to charge and tamp a mine with the aid of men working with Proto apparatus. Seventeen rescue men of the company were employed under the control of Lieutenant R. C. Smart, of the First Army Mine Rescue School.

The gallery ran out 100 ft. from the bottom of a vertical shaft 80 ft. deep, with a 16 ft. chamber at the end. While the length of the gallery was very favourable—few mines being charged so close to a main shaft—the dimensions and conditions were unfavourable, the last 40 ft. measuring only 3½ by 2½ ft., and having shaken sides and a bad floor.

Two rescue men, with the aid of a fatigue man, charged and supervised all apparatus before issue. Two rescue teams carried out the work underground: (1) officer and six men; (2) N.C.O. (company instructor) and six men.

Charging by rescue men with ammonal in 50-lb. tins was impracticable, and double sandbags, containing about 20 lb. of explosive, were used instead.

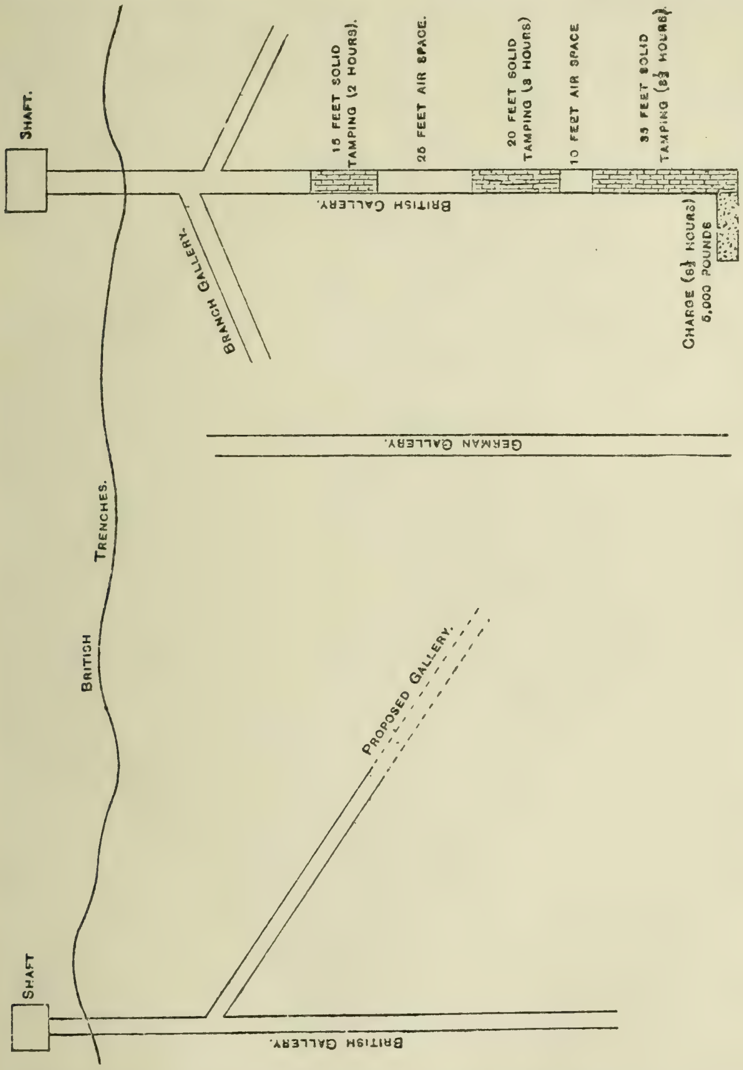

Fig. 12.—Diagram of British mine galleries, showing amount of charge and tamping laid by men wearing rescue apparatus.

During a period of forty-three hours the two shifts worked in reliefs of about two hours. It took seven hours (including a break of one hour in order to see the effect of tamping on the gas) to put in 5,000 lb. of ammonal, the last 1,000 lb. being placed in an hour. Altogether, 65 ft. of solid tamping were put in, the actual time taken to put in the charge and tamping being sixteen hours. Eighty-six twin cylinders and ninety miners' electric lights were used, a liberal reserve of apparatus and spares having been provided by the school. During periods of resting, numerous odd jobs in connection with ventilation, lighting, etc., were done. Actually, each man did about ten hours' work underground. There was no accident from defective apparatus which speaks volumes for the efficiency of the school junior instructor (Sapper Truman, R.E.), who supervised all apparatus before issuing it to the men.

The charge was laid and the mine sprung in time to save the situation.

(3) In a certain mining sector, owing to the large number of blows, the ground had become saturated with gas. While driving through this area, considerable trouble was experienced with men being gassed. As it was of vital necessity for the safety of the mine system that work should proceed, the officer in charge resolved to use Proto apparatus to complete the work. The following work was carried out by men wearing rescue apparatus.:—

The chamber of the explosive charge which had been started was completed by pick work. In loading, Proto apparatus was used during the whole of the first day, a considerable part of the second day, and for four hours on the third day while tamping was being put in. After tamping had been completed no further trouble from gas was experienced.

Two men worked in the morning and afternoon shifts, working for one and a half to two hours at a time. In a shift of eight hours, they were able to go down twice for three hours. One man after working for two hours went down again after an hour's rest. These men made no complaint after completing their shift, and were not in any way exhausted or affected by the work.

(4) The enemy blew a camouflet which destroyed a considerable part of a gallery, cutting off more than 1,000 ft. of gallery leading to a chamber which had been completed and ready for charging, and was to be one of our biggest and most important offensive mines at the battle of Messines. It was found necessary to re-drive the gallery. While this was being done, constant trouble from gas was experienced, but overcome. Later on, however, there was an inrush of gas, which led to the death of three men. The bodies were brought to the surface in fifty minutes by rescue men who had to travel 2,500 ft. in a very narrow gallery.

In order to recover the rest of the gallery, it was resolved to work round the affected area, which appeared to be saturated with gas. But before work could be recommenced it was necessary, first of all, to build off the affected area and to improve the ventilation. This work was carried out by the company rescue men working in Proto apparatus, under the direction of Corporal Parry, the assistant instructor at the Mine Rescue School, in place of the company instructor, who had been killed a few days before.

Work was started on 30th April, and was completed on 4th May, 1917. The first work consisted chiefly of coupling and uncoupling the air-pipes at various points in the gallery, and testing how far in a fresh-air base for operations could be placed. On the second day the electric pump broke, and two men uncoupled the air-pipe and connected it to a Holman hand-pump. Later on, by hard work, the laying of the air-pipe right up to the face was completed. Next day gas was discovered at the face, a canary being affected in five minutes ; 15 ft. of tamping was then put in, but as gas still came through a large gas-tight dam was built. This consisted of 20 ft. of 4 ft. 3 in. by 2 ft. 3 in. solid tamping, and it took four and a half hours to complete, as only one man could work at a time. Just when this had been completed the enemy blew a mine, which fortunately did not damage this gallery. The rescue men in the mine retained their self-possession and proceeded out calmly. After resting, they went back to investigate the damage. This splendid work allowed 1,200 ft. of gallery to be recovered, the mine being charged and tamped the day before it was required. The work of this company in overcoming the gas difficulties, which at one time were so serious as to threaten the abandonment of this mine, was characterized by indomitable pluck and perseverance. This mine was the biggest one blown at the battle of Messines, the charge being considerably over 90,000 lb.

General Conclusions.—Mine rescue work must never be undertaken in a light-hearted manner. Most careful preparation should always be made and a scheme of work drawn up. It cannot be too strongly emphasized that efficiency of apparatus will not make up for want of organization, and that rescue apparatus which is not properly looked after and periodically inspected is little short of a death-trap.

There must be efficient control and supervision of the men. The great value of strict obedience to orders has already been insisted on. It is certain that much of the success in rescue work and actual mining operations carried out by men wearing apparatus under the most trying conditions was due to the fact that there was the strictest discipline. The want of discipline and the non-observance or disobedience of orders may involve a whole rescue party in disaster and seriously retard rescue work.

Although military mine systems were much less extensive than small collieries, and the length of roads to be traversed by the men much shorter, it must be remembered that rescue work had frequently to be carried out under shell fire, and surrounded by all the dangers, discomforts and difficulties of trench warfare. The strain on all ranks during the intensive mining activity preceding the Somme, Vimy, and Messines attacks can well be understood, and the fact that during the months preceding the attacks apparatus was used many hundreds of times with few accidents indicates the degree of skill attained.

Never before have training and rescue work been carried out on such an extensive scale. In one army school alone for many months no fewer than one hundred and twenty 100 cub. ft. cylinders of oxygen were used monthly, and in the same school and in the tunnelling companies administered by it 450 Proto and 250 Novita sets were in constant use. At least 1,500 Proto sets were distributed along the whole front, with over 500 more for training and reserve at mine rescue schools.

The result of mine rescue organization—one quite new to warfare—was that many valuable lives were saved and important assistance in other ways given to mine warfare. Many defects of apparatus were discovered and corrected during the intensive training in the schools and actual work in the front line, and valuable modifications were suggested and carried into effect.

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